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REPORT NO. R-673

LUBRICATION IN THE DRAWING OF STEEL CARTRIDGE CASES

SIXTH REPORT PROJECT 3/161

by

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ORDNANCE LABORATORY
FRANKFORD ARSENAL
PHILADELPHIA, PA.
November 1945

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LUBRICATION IN THE DRAWING OF STEEL CARTRIDGE CASES

SIXTH REPORT

PROJECT 3/161

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Previous Reports
R-260
R-292
R-293
R-318
R-469

OBJECT

To summarize and correlate the available information on lubrication in drawing steel cartridge cases.

SUMMARY

A summary and correlation of the information on lubrication in steel cartridge case drawing is herein presented plus some original data. Emulsion lubricants, tool surfaces, surface pretreatments and low melting solid lubricants are treated. Some methods of testing and their applicability are briefly summarized. Tapering lubrication is discussed.

Two appendices are included which provide background for the adequate use and selection of drawing lubricants. One involves the theoretical background of the subject and the other treats the application of theory to practice in its more general aspects.

It is recommended that lubrication practice for steel drawing utilize:

1. Dried soap or wax deposits, preferably plus very thin rust or immersion flash copper deposits.

2. Emulsion lubricants of special composition, as developed in this program, used in conjunction with a surface pretreatment to yield an immersion flash copper deposit, lead coating, rust coating, sulfide coating, or phosphate coating.

3. Either of the above to be used with carbide dies, highly polished, and high polished, preferably chrome-plated, punches.

AUTHORIZATION

F.A. Report T-1019 Sept. 1942

CONTENTS

APPENDIX I

THEORETICAL BACKGROUND OF DRAWING LUBRICATION

APPENDIX II

APPLICATION OF LUBRICATION THEORY TO DEEP DRAWING

PREFACE

This report attempts to summarize the available information on lubrication in drawing steel, particularly, steel cartridge cases. This includes information obtained at Frankford Arsenal and by the contractors who made steel cases. The most important data from previous publications are summarized and a small amount of original data included.

In addition, there are included, as appendices, two sections that serve to provide background material for the understanding and usage of lubricants in this application and are references for certain phases of the subject that cannot be adequately discussed in the first section without losing continuity.

I. INTRODUCTION

In the early phases of development of a drawing problem, mechanical design is more primitive than in later phases and the lubricant is required to bear a greater burden. In addition, lubricant is an ideal "culprit" on which to blame failures. Hence it is not surprising that, on the basis of shop tests, certain lubricants used in the early phases of a development program are considered poor yet the same lubricants applied in the later phases of the program yield excellent results. Because of the metallurgical and engineering difficulties inherent in steel case manufacture, considerable emphasis was placed on lubrication and, as a consequence a considerable amount of information on this subject was accumulated This information is now also available for steel drawing operations other than cartridge cases.

Because of the necessity for this emphasis on lubrication, as well as the extremely rapid conversion of this project to the preliminary production phase, a good deal of confusion existed and gave rise to a rather peculiar situation. This is recorded here in the hope that future conditions of this sort may be avoided Thus, each manufacturer tested dozens of lubricants, frequently inadequately. As each manufacturer of drawing compounds submitted or sold a particular lubricant to one contractor, his representative approached the next contractor with the claim that the previous contractor was using his product (successfully, it is to be inferred By the time the first contractor found the lubricant inadequate, it had already been introduced into several other plants and was being tested. Largely because of the excessive number of lubricants submitted and the prevalence of mechanical and engineering difficulties, many of those lubricants were inadequately tested as evidenced by the condition in which four or five lubricants were finally used successfully by different contractors and each one of these had been rejected by other contractors as being inadequate.

II. EMULSION LUBRICANTS

A. Historical

The first lubricants tested in this application were those used commercially in drawing ferrous and non-ferrous metals. Those used for non-ferrous metals, in general, consisted of soap dispersions or emulsions of fatty matter and free fatty acids in water with soap as the emulsifying agent. These were shortly found inadequate and similar emulsions containing insoluble fillers and sulfurized fats and oils, which were used in other heavy drawing operations, were then tried with some promise, utilizing the steel drawing dies prevalent at that time.

Almost immediately after the beginning of the steel case program, the need for a laboratory method of evaluation became evident since about 100 different commercial products were submitted, most of which were accompanied by glowing claims. In addition, shop tests at that time were beset with many variables.

On the basis of theoretical considerations, it was believed that the factors governing steel drawing lubrication were mainly those of weld prevention. Consequently, extreme pressure lubricant testing machines, developed for testing hypoid gear lubricants, were surveyed to obtain a laboratory testing device. The weld preventive requisite was substantiated by the observations that most tool failures in drawing steel cases were due to build-up of metal on the dies and resultant scoring of the case pieces.

It was indicated after substantial correspondence that several companies were obtaining data on drawing lubricants with a Falex (Faville-LeVally) E. P. Lubricant Testing Machine (Fig. 1). Although several different procedures were being used, the procedure developed by the Crown Cork and Seal Co. of Baltimore, Md. seemed most promising [(1)*]. Some details of this procedure appeared to be too involved for the information desired and consequently, this procedure was simplified.

B. Use of the Falex Machine for Testing Emulsion Lubricants

In the Falex Machine a 1/4 inch journal initially makes line contact at four places with 2 V shaped bushings. Even after grooves have been worn, this limited area of contact makes it possible to develop very high unit pressures by the application of moderate loads. The journals are of SAE 2135 steel and have a hardness of 84-86 Rockwell B and the bushings are of SAE X1335 steel and have a hardness of 20 Rockwell C.

* These and subsequent numbers in parentheses refer to references at end of report.

The test is performed by "running-in" at a jaw load of 500 lbs. for 3 minutes, then increasing the load by 250 lb. increments and running for 1 minute at each increment. One criterion of performance was the condition of the test parts after running to 2750 lbs. jaw load. Another was the magnitude of the initial jaw load which, after a 1 minute run, caused sufficient wear to require 10 notches on the loading wheel to restore that load. This is indicative of wear on the test parts. A more detailed description of the test with specific data are available on previous reports. (2), (3), (4).

The data obtained in the Falex Test could be classified properly only if a particular batch of test parts were used and technique and operator were kept constant for each series of comparisons. This is not the ideal state of affairs but nevertheless it does provide a laboratory tool for preliminary evaluation of drawing lubricants. Needless to say, interpretation of data obtained in a laboratory test of the sort must be made with caution and perspective.

The data obtained by means of the Falex Test on dozens of commercial formulations divided these into several groups in relation to composition. Certain of the compounds containing insoluble fillers such as lithopone or chalk plus a sulfurized additive gave the best results. Compounds containing sulfurized additives without filler were next. Certain compounds containing fillers without sulfurized additives gave poorer results, although better than other filler bearing compounds or non-filler and non-sulfur bearing compounds. The Falex Test appeared to be somewhat more sensitive to the presence of sulfur and less sensitive to the presence of good fillers than shop test data. The specific data have been presented in previous reports R-190,[2] R-260,[3] and R-292[4]. There is presented in Tables I and II the general correlation between some results obtained with the Falex Test and some shop test results in the first draw of cal..30 steel cases[5]. The shop test data agree only fairly well in a specific sense but in a more general sense the above mentioned relationship among the various types of compounds that was found in the Falex Test was also found in the shop tests. This relationship among the lubricants also was borne out by many isolated results obtained in the artillery case program and other steel drawing operations and is also in accord with the general theory of lubrication discussed in the appendix. It may also be mentioned that two instances were obtained (Table II) in which the first sample of a compound gave good Falex and shop test results, whereas the second was poor in both tests. This gives an indication of one important usage to which this test can be put, namely, easy control of lubricant composition.

C. Development of Special Emulsion Lubricants

In performing these tests and considering the reports from the various contractors using emulsion types of compounds, it seemed evident that the greatest difficulties that were being experienced were due to lack of proper appreciation of the role of sulfur in these steel drawing lubricants, to sedimentation of the large quantities of filler present in these compounds, and to the high percentage of fatty matter required to maintain the high viscosity necessary to retard sedimentation.

In line with the first difficulty, it was observed that there was variation of the sulfur content of one brand that was used over a long period of time such different compositions were found under the same brand name. The manufacturer reported that no sulfur was added but that degras* was used in its manufacture. On that basis, two samples of commercial degras were obtained and were found to contain considerable, although widely varying, percentages of sulfur in highly reactive form. Investigation disclosed that the source of this sulfur is the sulfur and lime dip given sheep to remove ticks. However, nicotine is also frequently used for this purpose, and degras obtained from sheep subjected to this latter treatment would be free of sulfur. It is quite likely that this condition is responsible for some of the confusion on this subject since degras is commonly used in compounding drawing lubricants.

On the basis of the above, a laboratory program was initiated in an attempt to correct these difficulties and to obtain a better insight into the problem. In this program the Falex Test was used, and the final conclusions were checked by shop tests at a pilot plant line, in which it was possible to keep the variables under somewhat better control than in production.

The effect of sulfur in sheep wool was first confirmed[6] since emulsions containing the crude degras gave good results while those made up with the highly refined sheep wool fat (Lanolin) gave poor results (Table IV). Another important conclusion[6] was that it was not necessary to have any fatty matter present, since the mere addition of appropriate sulfurized additive to a soap dispersion yielded results as good as those obtained with the fat present. It may be observed that while soap solution was ineffective, soap solution containing 0.5% of a sulfurized additive was just as good as a commercial compound containing degras and chalk and lithopone filler. This conclusion was confirmed

* degras (American) is the material removed from the wool of sheep by means of scouring with an alkaline soap and recovered by acidification to decompose the soap and emulsion.

by considerable shop test data (Table III, Sec. A). The advantages of a lubricant of the former composition are manifold, some of these being low cost and ease of manufacture, use, and removal combined with good performance.

An important result of this investigation was the information that the particle size of the filler used in drawing compounds was highly important in determining the amount of filler that must be used to obtain good performance(7). Since the excess filler that is not actually contributing to lubrication is the major cause of the difficulties encountered with this type of lubricant, this is highly significant.

Experimentally, it was determined that as the size of the particles decreases, the quantity of filler required to give a good result in the Falex Test became smaller. In the range of particle sizes of whiting (chalk) of less than 1.5 microns diameter, approximately 3% of chalk gave good results (Table V) whereas 12% or more was required with coarser samples. This was confirmed by some shop test data (Table III, Sec. C). On this basis, it appears that in commercial lubricants the large quantities of filler are used solely to provide the smaller particles present to a minor extent in commercial fillers. The bulk of the filler sediments and is out of the sphere of action and at the same time results in the several difficulties mentioned previously.

Because of the small size of the particles in the above lubricant their rate of sedimentation is low and the amount of fat necessary to keep them in suspension is greatly reduced. In addition it is easier to remove the lubricant because there is less fat and filler present.

The combination of sulfurized additive and appropriate sized filler is indicated by the Falex Test to be superior to either alone. In this case, it is not desirable merely to suspend the filler in soap but rather to increase the viscosity of the dispersion somewhat by the addition of fatty matter and then to add the sulfurized additive. A dispersion containing 4% soap, 12% tallow, 3-4% of finely divided filler and 0.5% of a reactive sulfurized fatty base containing 12-20% sulfur has yielded promising results. The commercial filler used in these experiments was called Snowdown Brand Whiting from the Wagner Co. of Phila.

An advantage of these emulsion lubricants over dried deposits is that they can be used as the fluid in hydraulic strippers without special design and result in easier stripping with mechanical strippers.

Before leaving the subject of emulsion lubricants containing filler, it would be well briefly to discuss the fillers used commercially. In isolating the filler from one commercial lubricant it was observed that a considerable amount of coarser material was present which was found to be SiO_2(sand) in abrasive form. A number of proprietary lubricants were tested for abrasive silica and surprisingly high percentages were found in many cases[3]. This abrasive material could be derived from disintegration of the balls in ball mills or from the use of impure natural minerals. At any rate, the lubricants containing abrasive silica did not appear to be worse than those low in this constituent and it is probable that those particles settled faster and were not in the effective sphere of action. A commercial source of the small particle sized filler, found effective at low concentrations[7], was also found to have a small amount of insoluble silica, apparently without harmful effect.

Although the filler and sulfur-bearing lubricants were considerably better than lubricants without these constituents, it was found that in most cases there was required for adequate production some lubricant adjuncts, such as carbide dies and surface pretreatments, which were given increased consideration as a result of the steel cartridge case program.

III. CARBIDE DIES

One of the major contributions in preventing lubrication difficulties in steel case drawing was the wide-spread introduction of tungsten carbide dies. The lubricating action of these dies has been discussed in Appendix I. Some idea of the difference in magnitude of tool life with steel and carbide dies may be obtained from examination of Table III; the improvement is approximately ten fold. It may also be noted that the relative differences among lubricants were similar for steel and carbide dies. The big difficulties with carbide dies were breakage, expense, and re-processing. While the dies supplied early in the steel case program were rather brittle and frequently cracked in operation, the manufacturers were successful in overcoming this difficulty to a considerable extent in the later phases of the program. However, there were recurring instances of failures that were apparently due to flaws in the dies which resulted in the formation of small pits in the bearing surface. One tool man aptly summed up this situation by stating, "My dies either last less than an hour or many weeks." Another disadvantage of carbide dies is that mechanical failures, as may be due to improper indexing of the punch and die, are more expensive than with steel dies

A discussion of tool selection as a lubricant adjunct would not be adequate without a treatment of the effect of tool surfaces. Early in the experimental work conducted at the Arsenal experimental shop, it was observed that an increase in tool life of the order of 400% was obtained when steel dies were polished with a "lead lap" and fine abrasive, which gave a far better finish than the method that was used previously involving successively finer grades of emery paper[5]. Commercial practice in the artillery case program directed a great deal of attention to the preparation of surfaces, especially of punches. Highly polished or superfinished punches were used with or without chromium plate. It is also quite possible that part of the good performance of carbide dies is due to the great care with which these dies are finished to give a good surface.

IV. SURFACE PRETREATMENTS

Another important contribution of the steel cartridge case program, so far as lubrication is concerned, was the emphasis on surface pretreatments on the surfaces of the metal to be worked. These developments were not particularly new. Most of them were developed by the wire drawing industry, and some were developed for the drawing of seamless tubing. The pretreatments and deposition of solids that were important on the steel case program were as follows:

(a) Etching by pickling solutions

(b) Rough rolling

(c) Copper plating

(d) Lead Coating

(e) Sulfide Coating

(f) Phosphate Coating

(g) Rust Coating

These techniques have been discussed in more general perspective in the second appendix but will now be discussed in greater detail as applied to steel case drawing. Before discussing these pretreatments, a method for testing these will be described.

A. Use of a Low Speed Drawing Test

Attempts were made to utilize a low speed draw test in which the fourth draw of the cal..30 case was performed in a tensile testing machine at the rate of 3 inches/minute[9]. This test had yielded important information in brass drawing, but in drawing steel the forces required were the same when either unmodified emulsions or emulsions containing sulfur and filler additives were used. Carbide and steel dies also gave equal results in this test. Since these conclusions are frequently contrary to shop test data, this test is not completely valid in this application. However, it did give some valuable information on the frictional characteristics of various surface treatments which will be discussed.

B. Etching by Acid

Early in the program it was observed that smooth-rolled discs caused difficulty in cupping. This was especially true in drawing in those cases in which intermediate anneals were omitted. These difficulties were decreased when the surfaces were etched by treatment with acid. It was considered that these difficulties were due to inability of the lubricant to cling to a smooth surface. It is also conceivable, however, that the immediate surface was in the form of a layer which is hard and brittle. This surface layer would be readily removed by acid treatment because of the greater chemical reactivity of this material. At any rate, etching of case pieces between drawing operations was widely practiced in the steel case program to considerable advantage.

C. Rough rolling

It was found that for small arms cases, rough rolling could be substituted for the etching process in the cupping of discs. This was finally used in steel case manufacture as a method of preparation of the discs or strips that were to be processed into cups.

D. Copper plating

Rather early in the steel case program a very definite lubrication advantage was obtained in drawing small arms cases by electroplating approximately 0.002" of copper on the steel discs. This deposit was thick enough so that the copper remained on the surface through several draws and there was no necessity for etching in these cases. This technique had been employed in wire drawing and at least one instance had been reported in which light gauge metal strip for shaping operations is being electroplated right from the rolling mill line.

It was considered, however, that in the event that the steel case supplanted the brass case on a major scale, the electrolytic equipment required would be prohibitive.

Consequently, another technique was borrowed from the wire drawing industry. There had been developed a copper displacement bath that gave a bright, adherent, extremely thin copper deposit. This utilized a patented proprietary formulation called Cuprodine Salts[10]. Although the deposit formed was very thin, it nevertheless was large in comparison with inter-molecular distances. Therefore, this deposit was very effective although it had to be replaced between operations since the copper coating was usually broken near the base of the case. This technique was almost universally adopted for small arms cases[11]. It was used for a very short period of time by one contractor on artillery cases, with reportedly promising results, but its use was prohibited by directive shortly afterwards. The only reason ascertained for this directive was that the process used copper salts which were critical at that time. However, this argument does not appear to be very strong on the basis of the small amount of copper required (Cuprodine salts contain 28% copper). The bath is used at a concentration of 3-5% salts in 3% sulfuric acid. This technique appears promising and is considered desirable as a surface pretreatment. It may be seen from the data in Table VIII that this treatment results in reduced draw forces, particularly with emulsion lubricants. In addition, it was found that in shop tests on cal..30 and cal..50 steel cases there was a sharp increase in tool life for cuprodined pieces as compared with non-cuprodined pieces with both steel and carbide dies; this increase was greatest under conditions in which circulated emulsion lubricants were employed.

E. <u>Lead Coating</u>

One manufacturer[12] utilized a lead coating of .001" - .002" thickness obtained by dipping the case pieces into a flux, then into a molten lead bath containing about 7% tin, and finally into a chamber where the excess lead was removed by centrifugal force. This was applied at alternate drawing operations. This has yielded very good drawing performance when used in conjunction with non-pigmented, non-sulfurized emulsions and carbide dies. This company had previously been using such lead coatings for corrosion resistance and consequently had the required experience. There are some disadvantages to the system, such as the burning-out of lead pots, poisonous nature of the lead, necessity for skimming the lead pot and scraping the centrifugal chamber, use of critical tin, etc. In addition, when 90 mm discs coated with lead were cupped at Frankford Arsenal the lead was extruded off and was ineffective, indicating the necessity for special experience with this type of coating.

Both the copper and lead provide dissimilar metal to the two steel surfaces so that the tendency for welding is reduced. Being ductile metals, the force required for deformation is not as great with these deposits as with coatings like sulfide (Table VIII).

It was also reported by one contractor making artillery steel cases that good performance was obtained by using a 0.0005" electrodeposit of silver on the disc. This deposit survived all of the drawing operations and provided a fair measure of corrosion resistance as well. The high cost of the silver was more than balanced by reduction in pickling and cleaning operations between draws.

F. Sulfide Coating

Quite early in the steel case program a sulfurized tallow containing small amounts of water was used in the drawing of 105 mm cases. This method[13] was adopted from the plants drawing seamless steel tubing. The work was immersed in the molten lubricant until a black deposit was formed on the surface and the excess drained off to leave a thin film of tallow. The work was then drawn, usually in the absence of applied coolant. This lubricant had a most disagreeable odor and some difficulty was met in attempting to heat the oil and water mixture without bumping or spurting. In addition the water had to be replaced periodically.

Several of the manufacturers tested this method and discarded it mainly because of the disagreeable odor and messy appearance.

One of the most successful contractors modified this method to use a sulfurized soluble oil to supply the sulfide (or partially oxidized sulfide) coating and circulated a coolant of similar composition at the press[12]. While this product had a less offensive odor than the sulfurized tallow and water, it was still very messy and disagreeable. In addition, the heat generated during drawing is greater because of the higher resistance towards deformation of sulfide deposits, (Table VIII).

G. Phosphate Coatings

A small amount of experience was accumulated with phosphate coatings, particularly by the Bonderite process[14]. This process did not attain widespread use in this country although one manufacturer reported good results for this when used in conjunction with a circulated filler bearing lubricant (Table VI). The greatest disadvantage ascribed to this system by the contractor was that the filler settled out. This, however, may be reduced by the use of the special filler-bearing lubricant described earlier in this report.

This phosphate coating followed by a prolonged (45 min.) soak in dilute soap solution was widely used by French plants manufacturing steel cases for the Germans. Good performance has been reported for this procedure.

H. Rust Coatings

The use of rust as a drawing lubricant dates back several centuries to the early days of development of the wire drawing art. The procedure developed in drawing steel wire had an influence on lubrication in steel case drawing so that it may be well to digress for a while and give some specific information on this.

In the dry process[15] [16] of wire drawing the coils of wire are usually pickled and inadequately rinsed. They are then stored until the desired film of rust or hydrated oxide called the "sull" is formed. After this point it is placed in milk of lime to prevent further oxidation and baked at about 100°C. to drive off occluded hydrogen. The wire or rod is then immersed in either a fatty material, powdered soap or other plastic material before it enters the die. Usually the wire is passed through several dies before being annealed and relubricated. Powdered soap is the lubricant most frequently used with the sull and lime coating. A great disadvantage of the lime coating is that it accumulates at the throat of the die; it is this factor which precludes its use in steel case drawing.

A "sull" coating on steel cases was used by several contractors in conjunction with circulated pigmented lubricants but the reports on its performance were not as promising as with some other lubricants (Table VI). This may have been due to improper deposits since rust coatings are somewhat more difficult to control.

V. LOW MELTING SOLID LUBRICANTS (DRIED DEPOSITS)

A. Dried Soap Coatings

1. General

Solid soap deposits have been used as lubricants in steel wire drawing for a long time. Although powdered soap is used for the first draft (draw), this is converted into a continuous coating during this draft and is then used for one or more additional drafts. In addition, dried fat or wax and soap emulsions were used in wire drawing and the drawing of steel auto parts. The Bridgeport Brass Co. successfully utilized dried soap as the sole lubricant in brass cartridge case drawing. However, it remained for the steel cartridge case program to accentuate and emphasize this method. The pioneers in this were the Norris Stamping Co.[17], which utilized an unmodified soda tallow soap, and the Corcoran Brown Co.[18] which used a soap containing a major proportion of borax and water with only about 25% soap. This dried coating technique was widely adopted by artillery steel case manufacturers and is one of the most promising lubrication techniques for cartridge case drawing. As such it deserves a rather complete discussion in this report.

It may be pointed out that in almost all cases the application of dried soap deposits followed pickling operations. This resulted in more or less rusting. There is reason to suspect that these light rust films play an important role in this lubrication technique since several unconfirmed reports have been received indicating worse results when rust is absent. On the other hand, the Norris Stamping Co. reports that when rusting is excessive the pieces must be repickled to obtain good performance.

It appears that the physical form of the deposit rather than the chemical composition is the factor governing the performance of dried deposits. Thus, some experimental results were obtained in drawing cal..30 steel cases with dried deposits from a concentrated soap solution and from an equally concentrated emulsion containing fat, sulfurized fatty oil and chalk filler in addition to the soap. The emulsion resulted in a deposit that was soft and somewhat tacky whereas the soap deposit from a soda tallow soap was considerably harder. The shop test data (Table X) showed that the deposit obtained from the emulsion was considerably inferior to that from unmodified soap, even though the additional weld preventives were present.

2. Application

The general method of application of the dried soap coatings was as follows: The soap was dissolved in hot water to the extent of from 12 oz./gal. to 22 oz./gal. The actual concentration was usually selected such that under the conditions of application the coating was not visibly perceptible but could be detected as a small deposit upon running a fingernail along a distance of approximately 2 inches. The soap is maintained at different temperatures for different means of application. Some examples of these that were successfully used in the steel case program are as follows:

(a) Dipping Method. The work is racked so that cases do not touch at the sides and then immersed in the soap solution (12 to 22 oz./gal) maintained at 180°-210°F. The work is allowed to remain in the hot solution for 3-5 minutes in order that it may become hot and cause the water to evaporate more rapidly upon being withdrawn. The racked case pieces are withdrawn and allowed to drain to prevent the formation of pockets of lubricant on the inside and to allow evaporation of the water.

(b) Flow Method. The case pieces are placed on a conveyor system and brought into the chamber of a machine in which soap solution (about 20 oz./gal.) is pumped into the inside and flowed over the outside of the draw piece. The soap solution is maintained at 160-180°F.

(c) Spray Method. The case pieces are sprayed with soap solution (16-18 oz./gal.) maintained at about 140°F.

(d) Rumbler Method. This method has been used in the case of small arms cases for coating with oil and soap emulsions rather than soap solutions. The rubbing of the case pieces against one another tends to remove the deposit, but this has been used successfully, mainly because the coating required for good performance is very thin.

After being coated with soap by the above methods it is necessary to remove the water as completely as possible. The success of the dried soap method depends to a large extent on the dryness of the deposit. In the case of the dipping method, the heat of the case pieces themselves is relied upon to remove the water. This has been successfully done commercially but allows less control than baking methods. In the flowing and spraying methods the conveyor carries the case pieces into a chamber through which hot air at about 300°F. is being circulated. The time for this treatment is adjusted to yield a dry deposit.

3. Concentration.

It may be observed that there is considerable variation in the concentrations used by various contractors. Some of the contractors had obtained good performance from films so thin as to be barely perceptible even on repeatedly running a fingernail over the surface. This was also found to be the case in some experiments on cal..30 steel cases at the pilot plant set up at this Arsenal. While extremely thin films are preferable on the basis that less material accumulates at the throat of the die, this condition sometimes makes it difficult to determine whether any coating is present. Hence it is desirable to have a sufficient thickness as to be discernable upon running a fingernail along the case. Some low speed drawing test data for various soap concentrations are given in Table IX.

4. Excessive Lubricant on the Inside of Cases.

In some experiments on the use of dried soap as the lubricant in drawing brass cases, it was observed that case pieces fractured when an excess of soap, especially that which was incompletely dried, was present on the inside of the case piece. In some of these cases pieces in which fracture did not occur, there was a sharp rise in drawing tonnages. This same effect has been reported by Swift [20] for steel discs. It is quite probable that this can occur with steel case pieces in the event that an excess of liquid lubricant is present on the inside of the case piece. One possible source of this condition is the use of a water-base lubricant in hydraulic strippers in such a way that some liquid clinging to the punch is introduced into the next case piece; another cause is improper drainage of the case pieces.

5. Type of soap.

There were two general types of soaps used in this program viz: unmodified tallow soda soap and built-up soaps containing large quantities of alkaline salts. Some proprietary formulations of the latter type were Gilron 1033, F. S. Sales 638, Chandler 91. The first of those, particularly, was widely used and contained about 50% borax, as did also the Chandler 91 (40% borax). The F. S. Sales 638 contained a mixture of alkaline salts including sodium metasilicate (12).

Some experimental work on cal..30 cases at an Arsenal pilot plant set-up indicated that there is no difference in performance between these soaps and unmodified tallow soda soap. Excellent results have also been obtained by some of the most successful contractors with unmodified tallow soap. The claim has been made for the built-up soaps that they dry more readily than unmodified soaps. While the salts in these soaps crystallize readily giving this impression of quicker setting, it is considered that the rate of evaporation is the same in each case. The disadvantages of the built-up soaps are:

a. The proprietary formulations are overpriced.

b. Larger quantities of soap are required for a particular film thickness.

c. The coating is more brittle and apt to be chipped off.

d. Some of the alkaline salts tend to absorb moisture which is extremely detrimental to this type of lubrication.

6. Foaming.

A major problem in using hot soap solutions has been excessive foaming. This has been especially true in cases in which live steam has been used as a source of heat, as is inevitable in many plants. Norris Stamping Co. reports that excessive foaming can be kept under control by preventing the temperature from dropping below 160°F. Other contractors used various anti-foaming agents. The use of kerosene was reported at one plant. The use of small amounts of petroleum solvents such as Varsol has been found to be effective at Frankford Arsenal in controlling the foaming of 1/2 to 2% soap dispersions.

7. Powdering.

The powdering of the soap on cases during handling was a problem. One plant solved this by installing exhaust vents at the presses; another supplied personnel with protective masks. One of the plants that circulated oil as a collant did not have this difficulty.

8. Stripping of Case Pieces.

In removing the case pieces from the punch in the later draws some difficulties were experienced with mechanical strippers when using dried soap deposits. This is one disadvantage of this type of lubrication, since the lubricant itself cannot be used as the fluid in hydraulic strippers. The major aspects of this difficulty were settled by using an emulsion lubricant only as a hydraulic fluid. Since an excess of liquid on the inside of cases can cause trouble, as mentioned above, care must be exercised to keep this to a minimum and some ingenous devices have been made to avoid this.

9. Coolant.

In the early part of the program some contractors used a low viscosity oil* as a coolant. This served, in addition, to keep the powdering of the soap to a minimum. However, the larger number of contractors did not use a coolant and no difficulties were reported in this respect, except a higher temperature level of the tools.

B. Wax Coatings.

The good performance of low melting, solid coatings is by no means confined to dried soap deposits. The low speed drawing test results for several waxes were found to be the same or better than those for dried soap (Table VIII). Williams (19) has pointed out that the application of certain wax deposits causes large decreases in the back pull of a wire drawing machine.

These results have been confirmed by the production test results obtained by two contractors to the Navy Department with wax emulsions (13) that were dried on the cases. The production figures in those cases compared favorably with dried soap deposits. Good performance has also been obtained at Frankford Arsenal with deposits from wax emulsions.

The particular wax that has achieved considerable popularity in this application is Plastool 268. This is a 10% wax emulsion in water and is diluted with 1/2 to 1 part of water.

*For some time a light mineral oil containing 5% lard oil was used. Some experiments in drawing cal..30 steel cases in the pilot plant set-up at this Arsenal indicated that an unmodified petroleum oil of viscosity of 100 sec/100°F. S.U.V. was equally satisfactory. Since the former oil cost 85 cents/gal and the latter 17 cents/gal, this is a factor to be considered.

On the basis of the above, it is quite probable that a good many low melting, plastic, solid coatings are as suitable as dried soap. Some of these may be preferable to soap in compensating for the tendency for some soaps to absorb moisture on storage in moist atmospheres (which destroys its effectiveness) and in providing some temporary corrosion resistance between operations.

VI. TAPERING LUBRICANTS

At various stages of the steel case program difficulties were experienced in tapering the cases. One of the most important factors so far as lubrication is concerned was application of the proper amount of lubricant since, in these operations, excessive lubricant resulted in bubbles or folds while insufficient lubrication resulted in die build-up and scoring. Some contractors using dried soap in drawing were quite successful in utilizing the residual soap film plus a very thin film of light or medium mineral oil or fatty-mineral oil. Other contractors utilized undiluted paste type compound smeared to give a light film. Still others were successful in using thin films of lard oil or sulfurized oils. As in drawing, the introduction of carbide dies resulted in considerable decrease of lubrication difficulties in comparison with steel dies in tapering operations.

VII. RECOMMENDATIONS

The following lubrication methods, on which specific data are available in this report, seem most capable of supplying adequate lubrication in steel drawing under most conditions:

1. Dried soap or wax deposits, preferably over a very thin rust or immersion flash copper deposit.

2. Emulsion lubricants containing moderate amounts of reactive sulfur and filler (preferably of very small particle size) used in conjunction with a surface pretreatment to yield a thin film of immersion flash copper, lead coating, rust coating, sulfide coating, or phosphate coating.

3. Carbide dies of appropriate composition and quality and smooth, preferably chrome-plated, punches used in conjunction with either of the above.

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TABLE I

Correlation Between Some Falex Test Data and Some Controlled Shop Test Data Obtained in the First Draw of Cal..30 Steel Case with Steel Dies

Lubricant	Ranking in Shop Test	Composition	Falex Test Results Transition Point# A	B	C
Alco DA10 Spec.	1	Filler+Sulfur**	-*	-	-
Alco DA10	2	Filler+Sulfur	2830*	3000	2830
Houghtodraw 160	1	Filler+Sulfur	-*	-	-
Shelldraw S-1	3	Filler+Sulfur	2750	3000	2750
Richards FS + Sulf. Base V	3	Filler+Sulfur	2830	3000	2750
Gilron 155	3	Filler+Sulfur***	2830	3000	2750
Ironsides AF-11	2	Filler	2375	2830	1560
Richards S Spec.	4	Sulfur****	2250	1750	1750
Richards S Sulf. Base + V	-	Sulfur	2670	3000	2420
Steelskin CB-1	5	No. E.P. Add.	1750	1250	1500

* In another series of tests these three gave equal Falex results which were better than those obtained with Gilron 155 or Richards FS.

** Filler of smaller particle size than Alco DA10.

*** Sulfur content a haphazard constituent of the degras content.

**** Very low concentration of sulfur.

\# See Table IV

TABLE II

Some Representative Shop Test Data Obtained in the First Draw of Cal..30 Steel Cases Using Cuprodined Pieces and "Lead-Lapped" Graph-Tung Steel Dies

Lubricant	Die Life Tools A	Die Life Tools B	Die Life Tools C
Gilron 155	8,549	4,735 8,415 7,854	11,360
Ironsides AF11	15,378	9,141 11,121	-
Alco DA 10	23,298	7,590 7,029	-
Alco DA 10 Special		10,858	13,984
Houghtodraw 160		10,294 13,850	-
Steelskin 72 Batch I*		12,870	
Batch II**		4,140	

* High Falex Test Values
** Low Falex Test Values

TABLE III

Shop Test Data Obtained in the First Draw of Cal..30 Steel Cases Utilizing Cuprodined Surfaces

	Lubricant	Die Life Tools D#	Tools E	Tools F	Tools G	Tools H	Tools I	Tools J
A-1	Gilron 155	130,000	1800 2600		-	-	-	-
2	2% Soap Solution*	16,000	1 to 5	-	-	-	-	-
3	2% Soap Solution plus 0.5% Quakerkut 45**	134,000	2120	-				
4	1% Diglycol stearate***	50.000	-	1 1730	-	-	-	-
B-1	Dried soap + 2% soap solution	-	-	1-5 480	-	-	-	-
2	Dried soap + oil coolant	-	-	2980	-	-	-	-
3	Dried Gilron 1033 + oil coolant	-	-	2560	-	-	-	-
4	Dried Ironside AF11 + oil coolant	-	-	3390			-	-
C-1	Soap + tallow emulsion*	-	-	-	-		5,888	650
2	Soap + tallow emulsion plus 2/2/3% special whiting***	-	-	-	-		19,584 26,048	2,112
3	Soap + tallow emulsion plus 2 2/3% good whiting*	-	-	-	-			400 385

* Low Falex Test Values

** High Falex Test Values

*** Intermediate to High Falex Test Values. In experiment C this whiting had a range of very small particle sizes; much smaller than those in C-3.

\# Tools included carbide dies; the remainder of the tools were of Graph-Tung Steel

TABLE IV

PERFORMANCE OF EMULSIONS WITH AND WITHOUT ADDITIVES IN THE FALEX TEST

Soda soap used as emulsifying agent. Each composition diluted 1:3 with water before usage.

Composition		Transition Point* A	B	C	Conditions of Test Parts
1. 8% soap 25% tallow	a)	2250	1750	1750	Poor
	b)	2500	1750	1750	Poor
2. 8% soap 25% dogras	a)	2750	2750	2750	Good**
Sample I	b)	2750	2750	2750	Good**
	c)	2750	2750	2500	Good**
	d)	3000	2750	2000	Good**
Sample II	e)	2750	3000	3000	Good**
	f)	3000	3000	3000	Good**
3. 8% soap 25% lanolin	a)	2000	1500	1500	Very poor
	b)	2000	2250	1750	Very poor
4. 8% soap 25% lanolin plus 2.5% Quakerdraw	a)	2750	2750	2500	Good**
	b)	3000	1500	2000	Fair**
45			2750		
5. 8% soap 25% lanolin plus 2.5% sulfurized lard oil	a)	2750	2750	2000	Fair***
	b)	3000	2500	2000	Fair***
6. 8% soap 25% tallow plus 2.5% Quakerdraw 45	a)	3000	2750	2250	Good***
	b)	2750	2750	2750	Very good***
	c)	3000	2750	2750	Very good***
7. 8% soap plus 2.5% Quakerdraw 45	a)	3000	2750	2750	Very good***
	b)	2750	2750	2750	Very good***

* Transition points determined as follows:

A. Jaw load at point at which, after 1 minute, wear occurs to such an extent that 10 or more teeth on the loading wheel are necessary to take up the additional clearance between journal and bearing and restore the jaw load to its initial value.

B. Jaw load at which a drop in torque reading occurs, during the 1 minute run, of 2 lb. inches or more.

C. Jaw load at which the slope of the jaw load vs. torque curve suddenly decreases.

** Test parts blackened by formation of sulfide.

*** Test parts blackened only within the wear scar.

TABLE V

Effect of Particle Size of Whiting Filler on Falex Test Results

Lubricant containing	Condition of Test Parts After Run to 2750# Load I	II
1. No filler	Very poor	Very poor
2. 12% unseparated filler	Poor	- -
3. 12% Fraction III	Fair	- -
4. 6% Fraction I	Poor	Poor
5. " " II	Poor	Poor
6. " " III	Fair	-
7. " " IV	Fair	Fair-Poor
8. " " V	Good	Fair-Good
9. 4% " V	Good	Good
10. 3% " V	Good	Fair-Good
11. 2% " V	Fair	Fair
12. 2% " VI	Fair	Fair
	Fair-good	Good

Note: Particle size of filler decreases as fraction number increases.

TABLE VI

DATA ON LUBRICATION PRACTICES IN THE DRAWING OF ARTILLERY STEEL CASES OBTAINED FROM QUESTIONNAIRE COMPLETED BY STEEL CASE MANUFACTURERS. CARBIDE DIES USED IN ALL CASES. SAE 1020 OR SAE 1025 STEEL BEING DRAWN

SIZE OF CASE #	PREPARATION OF PUNCH SURFACE	PREPARATION OF WORK SURFACE	DRIED-ON LUBRICANT	CIRCULATED LUBRICANT	DIE LIFE 1st Draw	2nd Draw	3rd Draw	4th Draw	5th Draw	REMARKS
20 mm A	Chrome-plated	Pickled	Gilron 1033 Soap	Gilron 1038 oil	150,000	200,000	200,000	200,000	150,000	
" " B	" "	"	Montgomery S-5	Warco 1673	8,000-10,000	10,000-12,000	10,000-12,000	12,000-15,000	6,000-8,000	Disagreeable
" " C	Ground & polished	"	Gilron 1033 Soap	-	25,000	25,000	25,000	25,000	25,000	
" " D	Chrome-plated	"	Gilron 1033 Soap	Gilron 1038 oil	100,000	150,000	150,000	150,000	150,000	Warco 1673 1st draw
" " E	Polished + buffed	"	Gilron 1033 Soap	Gilron 1038 oil	37,000	30,000	28,000	35,000	-	
" " F	Polished + chrome-plated	"	Gilron 1033 Soap	Gilron 1038 oil	3,000	3,000	3,000	3,000	3,000	6 draws
" " G	Polished + chrome-plated	"	Wadham's WPD-269	-	200,000	200,000	150,000	150,000	150,000	Disagreeable
" " H	Hand honed	Bonderized	-	Montgomery 617B	200,000	200,000	100,000	100,000	200,000	Pigment settles.
" " I	Chrome-plated	Pickled	Gilron 1033 Soap	Monco oil	150,000	150,000	150,000	150,000	150,000	No relubrication 3rd & 5th draws
37 mm A	Polished + buffed	Pickled + alk. wash	D.S. 630	D.S. 630	50,000	50,000	50,000	50,000	50,000	
" " B	Chrome-plated	Pickled + alk. wash	Gilron 1033 Soap	Gilron 573B + 1038 oil	25,000	30,000	30,000	5,000	5,000	573B for 3rd, 4th + 5th draws
" " C	Chrome-plated	Pickled + alk. wash	Gilron 1033 Soap	-	20,000	20,000	15,000	5,000	2,000	Sturaco + Kerosene in 5th draw
" " D	Superfinished + chrome-plated	Pickled + alk. wash	-	Houghton 622 + 360	5,000-10,000	4,000-8,000	3,000-8,000	2,000-6,000	1,000-5,000	Houghton 360 in 5th draw
" " E	Ground + polished	Pickled + alk. wash	Gilron 1033 Soap	Gilron 1050 oil	40,000	40,000	40,000	1,000	1,000	Oil circulated in 4th + 5th draws.

NLG.#13543-1

TABLE VI (Cont'd)

SIZE OF CASE*	PREPARATION OF PUNCH SURFACE	PREPARATION OF WORK SURFACE	DRIED-ON LUBRICANT	CIRCULATED LUBRICANT	DIE LIFE 1st Draw	2nd Draw	3rd Draw	4th Draw	5th Draw	REMARKS
37 mm F	Polished + chrome-plated	Pickled + alk. wash	-	Houghton 360	10,000	8,000	7,000	6,000	5,000	
" " G	Polished + chrome-plated	Pickled + alk. wash	Young Soap	-	50,000	50,000	50,000	50,000	50,000	Estimate based on 30,000 pieces
" " H	Polished + chrome-plated	Pickled + alk wash	Gilron 1033 Soap	Gilron 1038 and Garia 27A oils	15,000	12,000	10,000	10,000	-	
" " I	Polished + chrome-plated	Pickled + alk. wash	Wadham's WPD 269	International Ref. & Mfg. Co. Case Cpd. A	100,000	100,000	100,000	75,000	50,000	
40 mm A	Ground + Polished	Pickled + alk. wash	Gilron 1033 Soap	-	40,000	40,000	40,000	20,000	-	
" " B	Superfinishrd	Pickled + alk. wash	Arctic Soap Flakes	-	30,000	10,000-20,000	10,000-20,000	10,000-20,000	10,000-20,000	Liquid lub. on 5th draw only
" " C	Polished longitudinally	Pickled + Rusted	-	Fergusson 59A	5,000	5,000	500	3,000	250	
57 mm A	Chrome-plated	Pickled	-	Stanicool Sol. Oil	dies polished daily					Dip in sulfurized oil 4th draw
" " B	Ground and polished	Pickled	Gilron 1033 Soap	Gilron 1050 oil	2,000	2,000	1,000	700	400	Oil circulated in 4th & 5th draws only
" " C	Ground and Polished	"	Gilron 1033 Soap	Gilron 1038 oil	1,500	1,500	1,500	1,000	1,000	
75 mm	Polished	"	-	Spec. pigmented lubricant	15,000	15,000	15,000	2,000	-	Difficult to use
105 mm	Polished	Pickled + Rusted	-	Richards SB + Base V	20,000	20,000	20,000	20,000	10,000	Dies polished after 20,000

* A, B, C etc. refer to individual plants manufacturing cases of this size.

Mq. 13543-2

TABLE VIA

DATA ON LUBRICATION IN DRAWING SMALL ARMS STEEL CARTRIDGE CASES OBTAINED FROM QUESTIONNAIRES COMPLETED BY STEEL CASE MANUFACTURERS

PLANT	CASE SIZE	STEEL	DIE MATERIAL	PUNCH MATERIAL	PREPARATION OF PUNCH SURFACE	PREPARATION OF WORK SURFACE	DRIED ON LUBRICANT	CIRCULATED LUBRICANT	DIE LIFE 1st Draw	DIE LIFE 2nd Draw	DIE LIFE 3rd Draw	DIE LIFE 4th Draw	REMARKS
A	Cal..30	SAE 1020	Carbide	Steel	Finish ground, lapped, chromed, lapped	Pickled and Cuprodined	Lubro #19 Soap Chips	Soap Solution (Lee Soap Co.)	—	30,000-40,000	20,000-30,000	10,000-20,000	2nd draw top die chrome-plated, bottom die carbide
	" "	" "	Chrome-plated steel	"	"	"	"	" " "	5,000-10,000	—	—	—	———
B	" "	FXS-575 Rev. 1	Carbide	Tool Steel 1.0-1.2% C	Highly polished parallel to long axis.	"	"	Lubro 19 & soap solution (Purity Soap Co.)	150,000	150,000	150,000	150,000	———
C	Cal..50	SAE 1015	"	Steel 2% C	Superfinished	"	—	Zephyroid (DuBois Co.)	—	—	—	19,000-40,000	Does not count lapping to remove pickup-only diamond dust repolishing
D	" "	SAE 1015	"	Tool Steel 1.0-1.2% C	Polished with long axis, chrome-plate .0005"	"	Shell V-2151X	Vastolein (Richards Co)	100,000	100,000	100,000	—	Necessary to install special lubricant applicator
F	" "	SAE 1015	"	Tool Steel 1.0-1.2% C	Mirror polished Chrome-plated	"	"	Marco #1673	100,000	50,000	25,000	—	———
F	Cal..45	SAE 1015	"	Tool Steel	New-polished Used-chrome plated	"	—	Macco Prod. Co.	500,000	500,000	6-7 million	—	Identical Production using Lubro #2 (Richards Co.) and Chandler #1170
	" "	" "	Chrome plated steel	" "	"	"	—	" "	125,000	150,000	—	—	
G	Cal..30 carbine	SAE 1025	Carbide	Tool Steel	Chrome-plated	"	—	Quaker #74	100,000	200,000	150,000	—	Based on preliminary production
H	Cal..30	SAE 1035	"	" "	Polished	"	—	Gilron 155	100,000-200,000	100,000-200,000	100,000-200,000	100,000-200,000	Fairly difficult to use
								F.A. Steel Case Lub. Z-3	100,000-200,000	100,000-200,000	100,000-200,000	100,000-200,000	Easy to use, cheap, and easy to remove

H = Frankford Arsenal Ordnance Laboratory Experimental Shop

Neg # 13543-3

TABLE VII

Available Information Concerning Lubricants Mentioned in Tables VI and VIA

Lubricant	Information
Gilron 1033	A built-up soap containing about 50% borax, 25% water and 15% soap.
Gilron 1038 oil	A 5% lard oil - 95% mineral oil blend.
Montgomery S-5	A sulfurized tallow containing a small amount of water.
Wadham's WPD-269	A material similar to Montgomery S-5 except that it is sulfurized soluble oil.
Richards SB	A soap and fat emulsion containing a reactive sulfurized fatty oil.
Richards Base V	A "noncorrosive" sulfurized fatty oil base.
Sturaco	Sulfo-chlorinated fatty oil base.
Richards Lubro #19	A soap (15%) and mineral oil (35%) emulsion containing about 5% free fatty acid and little or no fat or fatty oil.
Zephyroid Compound	A potassium soap (65%) containing about 35% water and 0.3% free fatty acid.
Richards Vastolein	A potassium and sodium soap (25%) paste containing about 75% water and 0.3% free fatty acid.
Shell 2151V	A pigmented (chalk 40%) compound containing 35% soap, fat and fatty acids of which 10% is soap and 2% free fatty acid.
Gilron 155	A pigmented (chalk 15%) compound with a wool grease base (0.05% sulfur) containing 10% soap, 3% free fatty acid and 15% fat.
Warco 1673	A soluble oil containing 1.5% sulfur as sulfurized fatty oil, 2% chlorine and 50% fatty oil.
Quaker 74	A soluble oil.
Stanicool Sol. oil	Soluble oil.

TABLE VII (Cont'd)

Available Information Concerning Lubricants Mentioned in Tables VI and VIA

Lubricant	Information
Garia 27A, Monco Oil	Oils used in conjunction with dried soap coatings and probably resembling Gilron 1036 in composition.
Macco Prod. Lubricant, Lubro #2, Int. Ref. Co. Lub., Fergusson 39A, Chandler 1170.	Probably emulsions of soap and oil or fat and fatty acids plus water. Conventional type drawing lubricant.
Montgomery 617B	Pigmented compound.
FAZ-3	Soap and sulfurized additive.

TABLE VIII

LOW SPEED DRAWING TEST DATA FOR VARIOUS SURFACE PRETREATMENTS

4th Draw Cal..30 Steel Case at 3 inches/min.

Lubricant	1st Max. Force lbs.	1st Min. Force lbs.	2nd Max. Force lbs.	Lubrication Index lbs.
1. Emulsion - 31* (1:2) + Bare Steel	7060	2800	3100	12,960
2. Emulsion - 31 (1:2) + Cuprodined	5640	2490	2960	11,090
3. Dried Soap - 12 oz./gal. Bare Steel	5780	2320	2960	11,010
4. Dried Soap - 12 oz./gal Cuprodined	5820	2260	2660	10,740
5. Emulsion - 31 (1:2)+Light Bonderite	5790	2740	3060	11,590
6. Emulsion 899** (1:8)+Sulfide from Sulfurized Soluble oil	6620	2830	3400	12,740
7. Similar 6 - Cuprodined prior to Sulfiding	6690	2870	3430	12,980
8. Similar to 6 - Sulfurized soluble oil Emulsion	6350	2540	3100	11,990
9. Dried wax Emulsion A + Bare Steel	5560	2330	2630	10,510
10. Dried wax Emulsion B + Bare Steel	5030	2190	2490	9,730

* Containing sulfur and finely divided chalk

** Unmodified fat and soap emulsion

TABLE IX

EFFECT OF CONCENTRATION OF SOAP USED FOR DRY COATING ON FORCES REQUIRED TO DRAW COPPER-COATED STEEL CASE PIECES

4th Draw Cal..30 Cases at 3 inches/min.

Concentration of tallow soda soap (FXS-405)	No. of Pieces	Lubrication Index
1. 3 oz/gal	10	13,140
2. 5 oz/gal	10	12,340
3. 5 oz/gal	15	10,810
4. 8 oz/gal	15	10,540
5. 11 oz/gal	15	10,790
6. 15 oz/gal	15	10,460

1-2 - Tool Set 20
3-6 - Tool Set 21

TABLE X

EFFECT OF PHYSICAL FORM OF DRIED DEPOSITS

Shop test data in drawing cal..30 steel case pieces with Graph-Tung Steel dies.

	Tool Life			
	3rd Draw		4th Draw	
(Dried deposit from)	Test I	Test II	Test I	Test II
1. Soap (12 oz/gal)	11,850	--	541	626
2. Emulsion lubricant containing additives*	1,216	5,200	320	302

* Composition

Soap	12%
Tallow	24%
Whiting	12%
Sulfurized additive	1 1/2%
Water	50 1/2%

APPENDIX I

THEORETICAL BACKGROUND OF DRAWING LUBRICATION

A. Friction

1. The Nature of Metal Surfaces

Metals are crystalline materials and their surfaces are similar to the bulk of the metal in many respects and dissimilar in many others. Depending upon the method of preparation of the surface, this will consist of many irregularities and fragmented crystals (Fig. 2). These are of irregular shape in the case of ordinary machined surfaces while in the case of Superfinished surfaces, which are prepared by one of the finest grinding techniques, much of the fragmented material is removed and the surface then consists of a series of broad plateaus and shallow valleys[37] (Fig. 3). In any event, the surfaces of machined or ground metals are not exactly plane and consist of a series of elevations and depressions of greater or lesser magnitude, depending upon the method of manufacture.

This being the case, when metal surfaces are pressed together or are allowed to slide over one another, the actual area of contact between them is considerably smaller than the apparent area of contact. Bowden and Tabor [3] have determined, by means of conductivity measurements, that in the case of lightly loaded surfaces the area of actual contact is as small as 1/170,000 of the apparent area. When the load is increased, the peaks on the surface tend to be plastically deformed and the area of actual contact is increased so that with very heavily loaded surfaces this area may be as high as 1/30 of the apparent area.

When the machining or grinding process is performed with tools or abrasives that are dull or glazed (loaded), there is a tendency for the metal to flow or be smeared over the surface rather than cut off. When the amount of metal which has been caused to flow in this manner is small, this has the effect of increasing the area of contact that may be realized when such metal surfaces are pressed together. On the other hand, when a considerable amount of metal has been deformed in this manner, there is a tendency for this metal to flake off when subjected to repeated sliding motions under high pressure. This is generally detrimental to the applications contemplated.[1] This surface layer has properties that are considerably different from the bulk of the metal, some of these being greater hardness, brittleness, and chemical reactivity. It has been reported that this layer is frequently transparent so that scratches below this layer are visible.

2. Sliding Friction

In the case of the sliding of dry or imperfectly lubricated surfaces over one another, friction has been found to conform to the Amontons Coulomb law(5).

$$F = \mu P$$

Where F is the friction, P, the total load, and μ, a constant of proportionality, which is commonly called the coefficient of friction. Friction, under these conditions, has been found to be independent of the apparent area of contact and the relative velocity of the surfaces, over a rather wide range of velocities, but is dependent upon the nature and surface of the metal. The reason for this lack of a relationship between friction and area had long been considered a mystery but is probably explained by the small area of actual contact between sliding metal surfaces as mentioned above.(4)

At one time it was considered that friction was due to an interlocking of the hills and valleys which constitute metal surfaces, (1, 21) but this view has been superseded by a more modern and logical concept based on the theory of molecular attractions (1, 14, 33). According to this concept, when portions of one metal come into very close proximity with another metal surface, the force of inter-molecular attraction becomes very large. This results in welding of the portions of the metal surfaces that are in contact to form a homogeneous region having similar properties to the metal in bulk form. Because of the irregular shape of most surfaces, this welding can only occur over the limited area in which the elevations are in contact, unless the surfaces are pressed together by very high unit pressures. In the latter case the metal flows and larger areas make contact and then weld. When welding takes place only at the elevations, the force required to break the welds is not necessarily very large. When metals are caused to slide upon one another, in the absence of very efficient lubrication, these welds form and are broken with extreme rapidity. The life of one of these welds, under conditions in which metals are caused to slide over one another at relatively high speed, has been estimated at 10^{-4} sec.(1). The work of Bowden and Leben (10) has indicated that, as a consequence of this welding, relative motion of surfaces sliding over one another takes place by means of a "stick-slip" process in which motion is momentarily arrested as each weld is formed and then proceeds as the weld is broken. This takes place so rapidly that it is not apparent except when highly refined methods of measurement are used. As each weld is broken, there is a flash of heat generated which results in extremely high temperatures, highly localized at the rubbing surface. In a series of experiments performed by Bowden and Ridler (12) in which the sliding metals were made portions of a thermocouple and the E.M.F. generated was measured, it was found that temperatures of 1000°C. or more were generated in the dry sliding of metal surfaces at relatively high speed (1200 cm/sec) although the bulk of the metal was only a few degrees above room temperature. While breaking of welds results in high temperatures, additional welding is facilitated as the temperature is increased. This may lead to a "vicious circle" resulting in large scale welding under appropriate conditions.

In the case in which softer metal is caused to slide over a harder metal, it has been found by Bowden, Tabor, and Moore (14) that the softer metal tends to be torn from its surface and retained on the surface of the harder metal as welded fragments, and at the same time, small portions of the harder metal are also torn off and are carried away with the softer metal (Fig. 4).

Some interesting evidence for this smearing of softer metals on harder metals has been obtained by Schnurmann (33) who found that while the smeared metal was not visible to the unaided eye, it was possible, by an ingenious method of development utilizing silver salts, to intensify this pattern of smeared metal so that it becomes visible.

3. Types of Friction

The welding between metal surfaces that has just been discussed is responsible for the greater part of frictional resistance. In addition, when lubrication is supplied to reduce welding and the thickness of the film of lubricant is appreciable, some frictional resistance is due to the resistance of the molecules of the lubricant themselves as they slide over one another. In the type of lubrication in which a thick film of liquid lubricant can be maintained between metal surfaces so that welding is almost absent, frictional resistance is almost completely dependent upon viscosity and upon the velocity gradient in the oil film. In another type of lubrication in which solid deposits are maintained between the surfaces, frictional resistance is dependent on the force required to cause plastic deformation of the deposit and friction of this type is considerably higher than for liquid lubricants. It is considered that insufficient attention has been paid by many authorities in this field, to the differentiation between these two forms of frictional resistance, and this is considered to be at least partially responsible for the confusion that exists in the literature on this subject. In this report, the frictional resistance will be classified into two types:

1. That due to welding of portions of the metal surfaces, and

2. That due to resistance of the molecules of lubricant toward sliding over one another. This may also be referred to as the force required for stress-deformation of the lubricant or lubricant friction.

4. Reduction of Friction

Because of the reactivity of metal surfaces, it is extremely difficult to prepare such surfaces free of contaminants, and even chemically clean surfaces have coatings of oxides of varying thickness, adsorbed layers of the chemicals used to clean them, and thin films of water vapor held tenaciously by physical or chemical forces of adsorption [20]. Surfaces that are somewhat cleaner than these can be obtained by means of abrasion [26]. Therefore, the laws of friction obtained for dry surfaces have really been developed on the basis of surfaces contaminated in this manner. The primary purpose of lubrication is to reduce friction of the first type, i.e. to interpose between metal surfaces a film of material which prevents the molecules of one surface from coming into sufficient contact with the other surface for welding to occur. This is true whether advantage is taken of the contaminants normally present on metal surfaces or materials are applied that are more commonly referred to as lubricants. When this purpose is completely accomplished, frictional resistance is due only to the lubricant friction and this type of lubrication is referred to as fluid, viscous, or thick film lubrication. On the other hand, it is frequently not possible to accomplish this purpose completely, and when this is the case, lubrication is attained by thin films of thickness from 1 to 2,000 molecules.[16] This type of lubrication is referred to as "boundary" or thin film lubrication and some welding friction is always obtained.

B. Types of Lubrication

Fluid lubrication takes place when the film of lubricant is so thick that the laws that apply to fluids in bulk are followed. A minimum film thickness for fluid lubrication conditions has been found by several investigators to be in the order of 10^{-4} cm. (15,26, 36,39). With a film thickness of this order of magnitude, the surfaces are separated to an extent sufficient to reduce the effect of intermolecular attraction to a negligible quantity. Since no welding takes place, frictional resistance is dependent mainly upon the viscosity of the lubricant and is independent of the nature of the surfaces. It is also dependent upon the relative velocities of the surfaces and the unit pressures. When the viscosity of a lubricant is greater than the minimum required to obtain a film sufficiently thick so that fluid lubrication is obtained, further increase in viscosity results in excess friction due to the extra work required to cause motion within the fluid.[24] In order to attain a sufficiently thick layer of lubricant for fluid lubrication, it is generally necessary to pay considerable attention to design and method of operation, i.e., clearances, oil feed, speed, etc. A large literature has been built up (24, 30) which concerns itself with this phase of lubrication so far as bearings are concerned, frequently to the exclusion or de-emphasis of other phases of the subject.

When true fluid lubrication conditions are attained, wear is absent, for example, an illustration has been cited in which large turbines operated under fluid lubrication conditions for more than 20 years have shown no appreciable signs of wear.[31] In addition to this, the coefficient of friction is at a very low value since no work is required to break welds between the metal surfaces. A comparison among the coefficients of friction for sliding surfaces under conditions of no (applied) lubrication, boundary lubrication, and fluid lubrication is given in Table I.[37]

When unit pressures are high and speeds are low, so that most lubricants tend to drain off, and under many other operating conditions, it is not possible to attain fluid lubrication. Under these conditions, lubrication is of the boundary type, and it is necessary to depend upon very thin films of lubricants. Under boundary lubrication conditions, friction conforms to the Amontons-Coulomb law for unlubricated surfaces, and lubricants of a different type (see section C) must be employed in order to obtain any sort of satisfactory performance.

As mentioned before, boundary lubrication conditions are especially likely to prevail when unit pressures are high. The relationship between applied total pressure and unit pressure is, of course, elementary and well-known. Nevertheless, in the design and operation of sliding surfaces, this relationship is frequently lost sight of, and dies with sharp approaches to the land or ball-bearings used under conditions in which some sliding occurs are too frequently found. This should be borne in mind in the analysis of lubrication problems since occasionally bearing surfaces that are apparently under low unit pressures have high unit pressure areas that prevent the formation of fluid lubrication conditions.

C. Boundary or Polar Lubrication

Boundary lubrication is accomplished by means of films that are adsorbed on metal surfaces by forces that are either physical (Van der Waal's adsorption) or chemical (chemisorption). The former type of adsorption results in films of lubricant which are held to the surface by weak forces of attraction and are consequently displaced with relative ease. As such, they are not efficient under conditions in which high shearing stresses are applied. On the other hand, chemisorbed lubricants are held to the surface very tenaciously. Chemisorption is usually monomolecular and frequently provides considerable improvement in lubrication. Intermediate between physical adsorption and chemisorption is another type in which the bonds between lubricant and metal are stronger than in the case of the former and weaker than the latter. This is due to orientation of polar lubricants and will be discussed later.

In addition to this strong attachment to the metal, there is required for good lubrication a portion of the lubricating molecule that is sufficiently large so that the sliding surfaces are kept apart to an appreciable extent. This effect has been found to be most efficiently provided by the use of fatty acids or similar materials in which the number of carbons in the chain is greater than 14.[11] It has been learned as a result of the classical researches of Langmuir [27] that fatty acids orient themselves with their active (carboxylic) groups at the surface and with the long chain of carbons standing out upright from the surface. Although this work was performed on water surfaces, substantial evidence for the formation of oriented fatty acids on metals has also been obtained.[40] As a consequence of this orientation, the surfaces are separated by a distance equal to twice the length of the chain of carbons when these fatty acids are adsorbed. This reduces the tendency towards welding and, in addition because of the lack of attraction of the hydrocarbon portions of the fatty acids towards one another, there is little resistance against slippage due to molecular cohesion of the lubricant.[32]

The work of Hardy[23] has shown that under boundary lubrication conditions the coefficient of friction is dependent upon the molecular weight or the length of the chain of carbons attached to the active group and is also dependent upon the reactivity of this group. The carboxylic group present in fatty acids was one of the most effective active groups. While materials consisting of an active group and a long chain of carbons were effective as lubricants, other materials containing the carbon atoms in the form of rings were relatively ineffective.[24] It has been since shown[11] that this is probably due to their orienting themselves with the long axes of the rings parallel to the surface so that the molecules do not stand out from the surface to as great a distance as in the case of long chains of carbons.

While monomolecular films of fatty acids are quite effective, as is evidenced by a decrease in the coefficient of friction from 1.0 to .13 in one series of experiments performed by Langmuir with glass surfaces,[28] they tend to be worn away quite rapidly.[11] It has, however, been found possible to build up controlled thicker layers of fatty acids. This has been done experimentally by an interesting technique devised by Langmuir and Blodgett [8, 28] in which monomolecular films of fatty acids may be picked up from water surfaces, one on top of the other. It was found as a result of X-ray measurements [16] that these layers were build up in such a manner that the carboxylic groups and the hydrocarbon groups were from different molecules forming doublets. It may thus be seen that it is possible to have layers of lubricant oriented perpendicular to the surfaces that are considerably thicker than the chemisorbed monomolecular film mentioned above. It is probable that when a lubricant which is effective under boundary lubrication conditions is applied to a metal surface, there are built up layers of oriented molecules to a considerable thickness. Some investigators have measured oriented films of polar molecules that were from 8500 to 20,000 Angstrom units thick, which is equivalent to 400 to 1000 molecules of fatty acids.[16] In the larger thicknesses, it has been found that the films were approaching dimensions sufficient for fluid lubrication. However, it is probable that under high unit pressures, a good many of these molecules are displaced.[22]

This orientation of polar molecules on metal surfaces is probably due to the fact that these molecules consist of two separate portions of opposite electrostatic charge. This results in the formation of a dipole so that the orientation may be likened to the alignment of small magnets in a magnetic field. When the polar molecules are diluted with a non-polar material such as mineral oil, the rate of formation of these oriented films depends upon the concentration of the polar molecules, and at very low concentrations it may take an hour, or more, for an oriented film of appreciable thickness to form.[25] When mixed polar molecules are used, there is preferential adsorption on the metal surface of the molecules with the more active group if these are present in concentration of more than 0.7%; under these conditions the coefficient of friction is almost the same as though the more active lubricant were present alone.[29]

It has been found that when the temperature of metal surfaces is raised to some 40 or 50°C. above the melting point of the fatty acids, a process of disorientation appears to take place which results in the disappearance of good boundary lubrication properties.[38] This effect may be important in view of the fact that Bowden and Ridler[12] have found temperatures in the order of 600°C. when surfaces were caused to rub against one another at high speed even when fairly efficient boundary lubricants were employed. This disorienting effect has also been observed in some experiments performed by the writer, in which relatively thick films of acid soap were adsorbed by prolonged immersion in dilute soap dispersions.[35] The thickness of the film adsorbed as well as lubrication performance was considerably reduced when the immersion was at 60°C. instead of room temperature. This effect complicates studies of boundary lubrication to a great extent since actual temperatures at metal surfaces under most conditions have not been accurately determined. This is especially true in the case of metal forming operations such as deep drawing in which heat is also generated by distortion of the metal. However, it is probable that surface temperatures are quite high.

It is obvious on the basis of our discussion of metal surfaces, that under lubricated conditions the rougher the surface the greater is the opportunity for contact between the high spots or peaks of the surfaces with consequent welding. The thicker the film of boundary lubricant adsorbed, the greater is the roughness of the surfaces that can be tolerated without these high spots making contact. Thus it appears that boundary lubricants are more effective when the surface of journal bearings are rougher.[3] It has been found generally advantageous to keep surface roughness to a minimum in which case unit pressures are also reduced because of the greater area of contact, and the thickness of boundary lubricant required for optimum performance is reduced.

It may be mentioned that the classical mechanism of boundary lubrication, due to separation of the surfaces by adsorbed films of oriented molecules with slippage taking place at the hydrocarbon or inert ends of the polar molecules, has been modified by Beeck and his co-workers.[5] These investigators found that at relatively high speeds, there was a drop in the coefficient of friction when polar molecules were used which was ascribed to a "wedging" effect in which additional quantities of lubricant were forced in between the layers of oriented molecules to cause greater separation of the metal surfaces and consequently better lubrication. However, it is probable that this type of effect can occur only under very special circumstances and that the former concept must still be applied to most boundary lubrication conditions. These authors also ascribe the beneficial effects due to boundary lubricants as being caused by a smoothing of metal surfaces which reduces unit pressures by increasing the area of contact.

While fatty acids with long chains are very effective boundary lubricants, they tend to cause corrosion when present in sufficiently high concentrations. This, for example, was a prime cause of discontinuance of the use of small quantities of fatty acids in motor car oils (germ Process).[43] Consequently, a great deal of work has been done to obtain polar lubricants that are not as corrosive as the fatty acids, and hundreds of such materials have been patented(47), usually under the designation of "oiliness" agents. It is considered that the term "oiliness", which is widely applied to the type of lubricants discussed in this section, is not sufficiently specific and because of its concept forming connotations has led to a great deal of confusion in this subject. It is believed that the terms "polar lubricants" and "boundary" or "polar lubrication" would be more apt in describing the phenomena discussed above and would reduce this confusion. The term "Boundary Film Strength" has recently been suggested(42) and this is far more satisfactory than "oiliness" although this term also has popular connotations that are not exactly applicable to lubrication of this type.

Although the use of polar lubricants results in great improvements in lubrication under severe operating conditions, when operating conditions are very severe, such as in the case where unit pressures are extremely high and temperatures are high, polar lubricants such as those discussed above are not able to separate the metal surfaces sufficiently. Under these conditions different types of lubricants, referred to as extreme pressure lubricants, must be employed.

D. Extreme Pressure Lubrication

Extreme pressure lubricants are materials that are capable of forming films of chemical compounds upon metal surfaces,(54) which are stable to high temperatures. These compounds serve to separate the surfaces so as to reduce the forces of intermolecular attraction. These compounds, moreover, are maintained on the surface quite tenaciously, partially because they are solid materials and partially because they are to a considerable extent held by forces equivalent to those involved in chemical reactions.

The development of extreme pressure lubricants and the theory of extreme pressure lubrication received great impetus in connection with the development of lubricants for hypoid gears for automotive applications. However, their use is by no means limited to those applications and is indicated under operating conditions in which pressures and temperatures are high. Their application to metal forming operations is, therefore, quite obvious. Although lubricants of this type were used in metal-forming operations far earlier than the application of hypoid gears to automobiles, the information obtained as a result of this application has enabled a far more logical approach to metal-forming lubrication which has resulted in great improvements in this field.

Oxygen, present in air, is one of the most common extreme pressure lubricants although it is not generally considered as such. Practically no metal surfaces are used commercially that are not covered by at least a thin film of oxide. Under many operating conditions this quantity of oxide is sufficient to prevent welding between metal surfaces and, at other times, an oxidation procedure is resorted to in order to obtain a film of sufficient thickness to resist the high unit pressures that are encountered.

Of the materials used as extreme pressure lubricants the most common is sulphur which is applied in the form of sulphurized mineral oils, flowers of sulphur, synthetic sulphur compounds or finely divided ("colloidal") elementary sulphur dispersed in some vehicle. Compounds containing chlorine and phosphorus are also used quite extensively. These materials react with metals to form sulphides, chlorides, and phosphides, respectively. While sulphur compounds are expected to form sulphide coatings, a recent paper in which X-ray analytical methods were used indicated that the action of elementary sulphur plus lead naphthenate on iron resulted mainly in the formation of lower oxides of iron and only occasionally in the formation of sulphides.(34) Nevertheless, it is considered that sulphides are formed under many other conditions and in the case of copper, the action of sulphurized oils has been shown to consist of sulphide formation.

In the case of sulphurized oils, the reactivity of the sulphur varies with the type of oil and the temperature and length of time during which the oil was treated with sulphur or sulphur chloride. Fatty oils treated with the sulphurizing medium for relatively long times at relatively high temperatures are of the type called "non-corrosive" for the reason that they do not blacken polished copper strips kept in contact with the oil at 100°C. for several minutes. On the other hand, treatment of the fatty oil with sulfur for a shorter time and at lower temperatures or treatment of many mineral oils results in sulphurized oils of greater reactivity. In the case of chlorine and phosphorus bearing extreme pressure lubricants, it is quite common to use relatively pure synthetic compounds, and the reactivity is thus dependent upon the choice of the molecular structure of the compound synthesized.

Because of the control of reactivity that can be obtained by suitably varying the method of preparation or by using well-defined synthetic products, it is possible to "tailor-make" lubricants to fit the widely varying needs of different metal-forming operations.

While relatively thick films of stable chemical compounds are very efficient in preventing welding, there is a tendency for thicker films to flake off due to the poor ductility of most of these deposits. If an excess of the extreme pressure lubricant is available, the metal surface, which is exposed as a result of this flaking, reacts almost immediately to form another protective film. However, this results in a loss of metal in the form of the chemical compound and is one form of wear as will be discussed further in the section on the Wear of Metals. Another difficulty that is experienced when relatively thick films of these non-ductile deposits are formed, is that high forces are required to deform the non-ductile deposit. In other words, the force required for stress deformation of the lubricant or lubricant friction is high. This may frequently be reduced by the addition of a suitable polar lubricant, but it is preferable to utilize an extreme pressure lubricant in which reactivity is not too great coupled with a polar lubricant for best results under most operating conditions. When the tendency toward welding is extremely great, however, the most reactive types must be used but the other disadvantages will also be obtained.

While the more commonly accepted view of the action of extreme pressure lubricants involves the formation of stable chemical compounds, a hypothesis has recently been advanced by Beeck(6) and his co-workers in which the action is considered to be one of polishing of the metal surfaces. According to this hypothesis, low melting eutectics are formed by reaction with the lubricant which then flow under the influence of applied pressure to form very smooth surfaces. This reduces unit pressures to a great extent and thus enables polar lubricants to become sufficiently effective to supply adequate lubrication. It appears probable that the smoothing of surfaces is one action of extreme pressure lubricants.

Any material that tends to prevent metal surfaces from welding under conditions of high pressure and temperature may be considered to be an extreme pressure lubricant. If this concept be accepted, then thin films of dissimilar metals which are sometimes interposed between metal surfaces as, for example, copper or lead in the case of steel surfaces or chemically inert filters such as chalk or talc may be considered as being extreme pressure lubricants.

Pertinent to the use of dissimilar metals as extreme pressure lubricants, it has been found (Table II) that the coefficient of friction (unlubricated) is lower when dissimilar metals are caused to slide upon one another than when the sliding metals are similar. This is apparently due to a decrease in the tendency for welding, which might be due to differences in crystal structure. It is generally advantageous to utilize films of ductile metals so that frictional resistance due to the lubricant is not very great. While the coefficient of friction is reduced by the use of films of dissimilar metals, the values are still sufficiently high so that they must be used in conjunction with other lubricants, especially in order to provide a weak link in the metal-lubricant-metal chain at which slippage is facilitated.

Another method that may be used to keep metal surfaces apart involves the use of chemically inert fillers, such as chalk or graphite, which become trapped between the metal surfaces under certain sliding conditions and thus serve as mechanical separators. Certain fillers that have weak cleavage planes, such as graphite or talc, have lower lubricant friction than those that pulverize under high pressure, such as chalk, but it is believed that they tend to be less efficient mechanical separators. Fillers will be discussed in greater detail in Appendix II of this report.

In discussions on extreme pressure lubrication three terms are widely used: (1) anti-weld activity, (2) film strength, and (3) load carrying capacity. Of these terms, "anti-weld activity," which is the most descriptive, is used in a limited sense to indicate the operation of extreme pressure lubrication under conditions so severe that welding cannot be completely prevented. Film strength is generally used with reference to the ability of polar lubricants, or other organic lubricants, to prevent welding although it is also frequently applied to the prevention of welding accomplished by the formation of stable chemical compounds which are predominantly inorganic. Load carrying capacity is more specifically applied to the latter case in which the typical extreme pressure lubricants are operative. Because of the confusion which this terminology gives rise to, it is believed that it would be preferable to use a term such as "welding preventive" or "welding prevention lubricant" in describing extreme pressure lubricants. However, the term "Boundary Film Strength" (42) may be used in referring to the welding preventive properties of polar lubricants.

E. Wear of Metals

The wear of metals may be classified into four types, as follows:

1. Wear due to welding
2. Oxidation or Reactivity Wear
3. Abrasive wear
4. Corrosive wear

The first type of wear is due to insufficient weld preventive and is usually quite rapid, resulting in tearing of the surfaces (scoring or galling). In certain cases, the action is localized in that a scratch is gouged from one of the metal surfaces or a piece of one metal surface is welded onto the other surface. In order to utilize these surfaces commercially it is usually necessary to remove the scratch or built-up metal by means of polishing or grinding. This grinding process results in the removal of metal from the entire surface which is an indirect result of welding wear.

The second type of wear is called oxidation wear by Fink [19] and has also been investigated by other workers (17, 33). This is considered by the writer to be a more universal phenomenon than Fink recognized. It is believed that the designation of "reactivity wear" would be more appropriate. This type of wear is due to the formation of relatively thick films of oxide, sulfide, chloride, or phosphide by reaction with a reactive extreme pressure lubricant. These films being rather brittle, are displaced from the metal surface when the more ductile metal beneath them is plastically deformed. Since an excess of reactive lubricant is available, a new film is formed almost immediately which prevents welding from taking place. This process, if continued for some time, results in the removal of metal from the surfaces at a uniform rate leaving a surface that is rather smooth.

It thus becomes apparent that to keep wear to a minimum, a sufficient thickness of weld preventive is necessary to keep the surfaces from making frequent contact, but increase in the thickness of the coating over this minimum results in an increased rate of wear. However, the rate of reactivity wear is usually much lower than that due to insufficient weld preventive so that a moderate excess of reactive lubricant is far to be preferred to any deficiency. In a great many applications, the thickness of stable compound necessary to keep the metal surfaces sufficiently far apart so that a low rate of wear due to welding is obtained is so small that the coating is invisible to the unaided eye.

Another method that may be utilized to a certain extent in reducing the rate of reactivity wear involves the adsorption of a film of polar lubricant in addition to the weld preventive. This serves to provide a region of easy slippage within the lubricant so that the tendency for displacement of the brittle deposit of stable compound is reduced.

A mechanism of wear reduction has been recently advanced [6] in which it is postulated that by the action of certain lubricants in removing surface irregularities the unit pressures and rate of wear are reduced. To a certain extent this concept is equivalent to the concept of wear given above, since this smoothing action may take place by virtue of the formation of stable chemical compounds on the surface followed by removal of the high spots by displacement upon repeated contact. Because of the excess of the extreme pressure lubricant, however, this protective film reforms and prevents welding. The proponents of the concept of reduced wear due to smoothing of surfaces, however, ascribe this effect to the formation of low melting eutectics that flow readily and thus form very smooth surfaces.

A great many wear studies have been performed for unlubricated surfaces, or at least surfaces that are not consciously lubricated in order to determine the wear resistance of metals and coatings on sliding surfaces. Under these conditions, wear has usually been considered as abrasive in nature, that is, a harder surface causes the chipping off of portions of the softer surface with which it makes contact. This type of wear is probably important under low pressures. However, many of these wear studies may have been faulty in the respect that there was no control of lubrication. Usually surfaces are used that are covered with layers of oxide or water vapor of greater or lesser thickness and these determine whether welding or reactivity types of wear will occur. However, these wear studies have determined that softer metals wear more than harder metals although a great many exceptions exist to this relationship. This is probably related to the experimental fact that soft metals weld more readily than harder metals (Table II). One series of investigations has indicated that the melting point of the metal rather than the hardness determines the rate of wear [9] indicating that something more than abrasion is involved.

Another type of wear is corrosive wear. In this condition, parts that are in intermittent sliding contact are corroded by exposure to a corrosive environment and during the sliding contact the corrosion products are displaced from the surface. In many cases this type of wear may be reduced by the use of protective finishes such as chromium plate or by the use of rust inhibiting oils. Corrosive wear is most frequently a result of the development of an acidic environment. This may be due to fatty acid present in the lubricant or formed by oxidation of mineral oil, hydrolysis of sulfur or chlorine bearing lubricants to form hydrosulfuric or hydrochloric acids, solution in water of the products of combustion of fuels to form carbonic and sulfurous acids etc. In the last case, wear of engine cylinders has been ascribed to the condensation of these acids on the cooler portions of the cylinders resulting in corrosion. In some cases, corrosion does not become appreciable until the surfaces are in sliding contact since the corrosion products ordinarily protect the surface from further corrosion. An example has been cited by Wise[44] that clearly illustrates this point. Base metal alloy fountain pen points resisted corrosion by ink under static conditions but when rubbed against paper the rate of wear was high. There is also some similarity between this condition and the reactivity type of wear discussed above.

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TABLE I

Comparison Among Various Types of Friction (from The Story of Superfinish (37))

Condition of Surfaces	Type of Friction	Coefficient of Friction: Range	Coefficient of Friction: Average
1. Unlubricated*	Dry friction	0.10 to 0.40	0.16*
2. Boundary lubricated	Boundary friction	0.01 to 0.10	0.03
3. Perfectly lubricated	Fluid friction	0.0001 to 0.01	0.006
4. Ball bearings	Rolling friction	0.001 to 0.003	0.002
5. Roller bearings	Rolling friction	0.002 to 0.007	0.005

* Surfaces covered with oxide and possible water vapor. Bowden and Hughes (9) have reported that values are increased to approximately 2.0 when surfaces are "outgassed" to remove oxide and friction is determined in a vacuum.

TABLE II

Coefficient of External Friction (μ) for various materials, after Tichvinsky and Schnurmann (21)

Combination of Materials	(μ)
Carbon - glass	0.18
Copper - mild steel	0.36
Garnet - mild steel	0.38
Glass - glass	0.40
Hard Steel - hard steel	0.42
Cadmium - mild steel	0.46
Ebonite - glass	0.53
Mild Steel - mild steel	0.57
Copper - copper	0.60
Nickel - mild steel	0.66
Cadmium - cadmium	0.80
Aluminum - aluminum	1.4

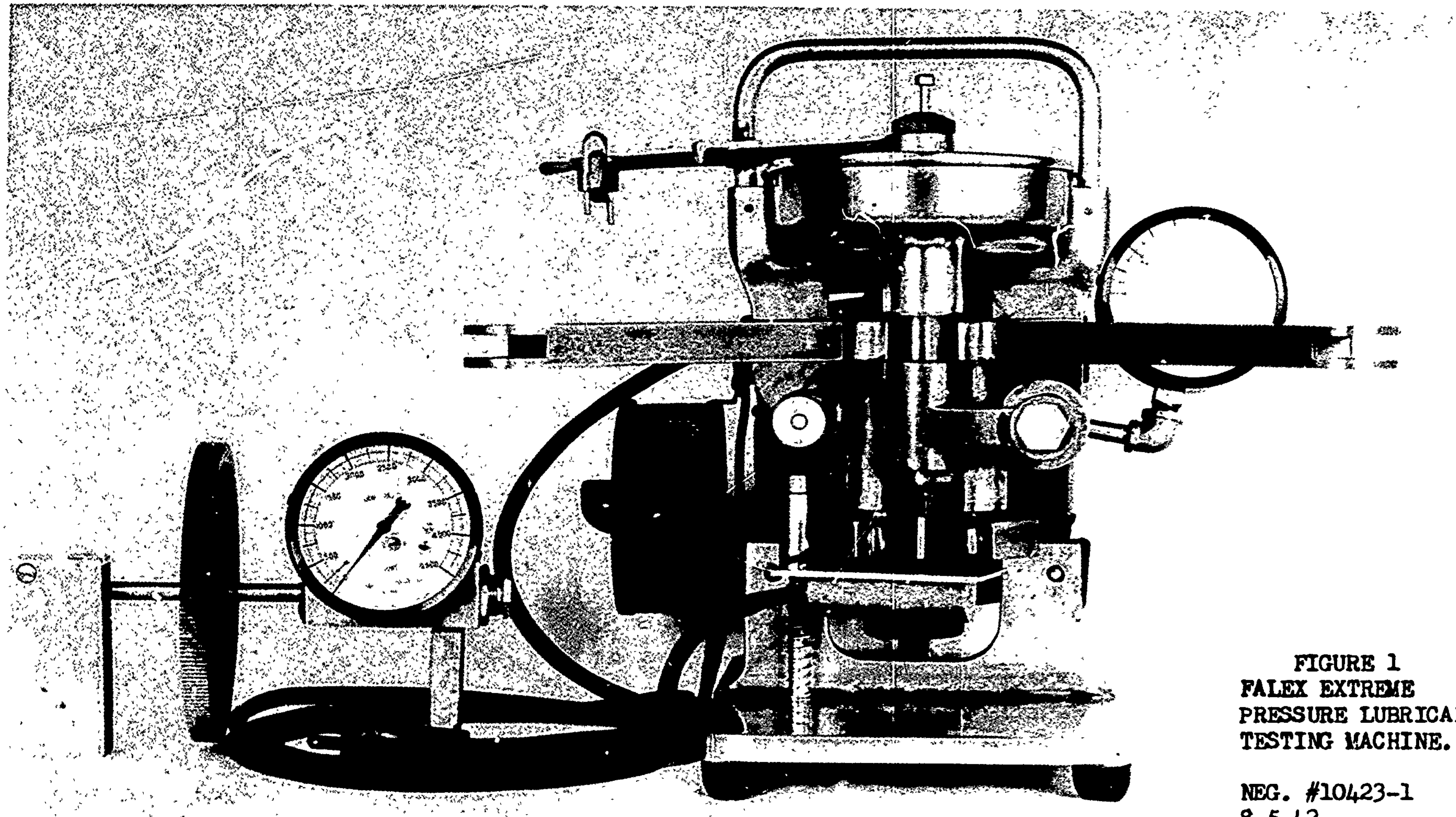


FIGURE 1
FALEX EXTREME
PRESSURE LUBRICANT
TESTING MACHINE.

NEG. #10423-1
8-5-42

177

One inch = .0013 inch

PHOTOMICROGRAPH OF PROFILE

Part	Test piece
Material	Steel
Operation	Fine turned
Profilometer	145 microinches rms.
Magnification	750 diameters

The profile of a finely turned steel surface will have the appearance shown in the above profile photomicrograph. That such a surface is fragmented is shown by the metallic particle in the upper right hand corner which apparently is loose from the body of the material. This particle may not necessarily be detached from the surface as it may be a portion of a curved projection extending up through the layer of plating holding the fragmented surface in place.

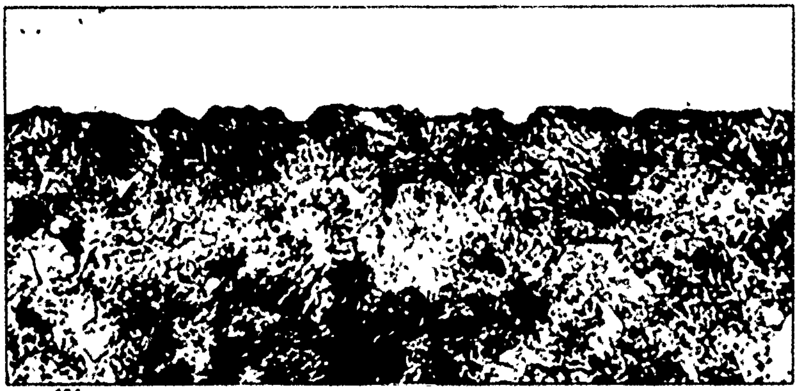
FIGURE II

NEG. #13650-1

31 MARCH 1944

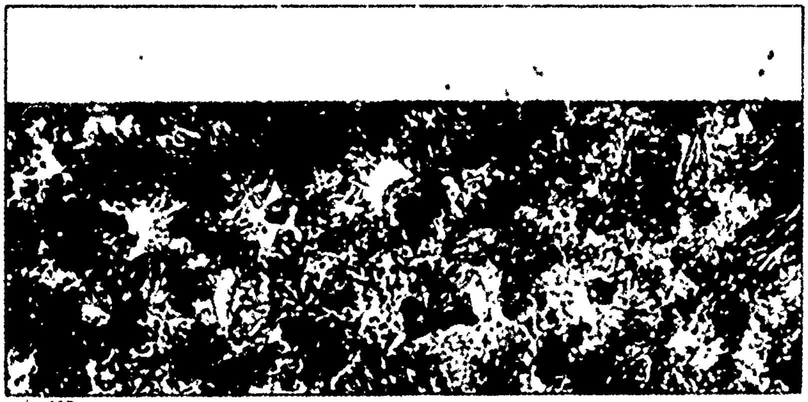
123
Operation ....Ground
Profilometer ....35 microinches rms.

One inch = .0013 inch.



124
Operation ....5 seconds SUPERFINISH
Profilometer ....20 microinches rms.

One inch = .0013 inch.



127
Operation ..............SUPERFINISHED
Profilometer ....0.9 microinches rms.

One inch = .0013 inch.

FIGURE III

NEG. #13650-2

31 MARCH 1944

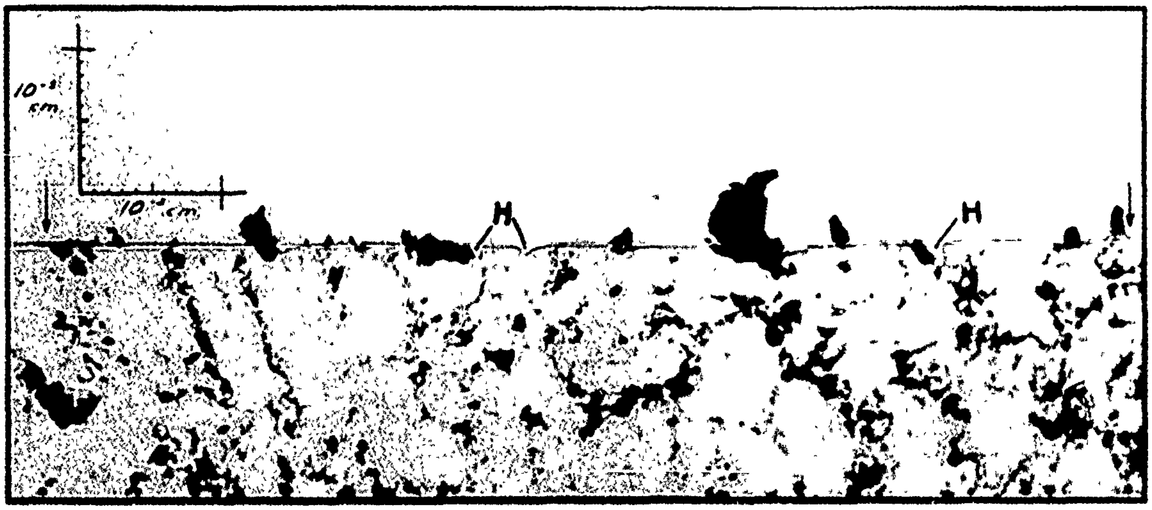


FIG. 2. Taper-section of track formed by sliding a hemispherical copper rider on an unlubricated steel surface. Horizontal magnification 200. Vertical magnification 2000. The width of the track is indicated by arrows. Note the adhering fragments of copper, and the pits marked *H* where the steel has been plucked out of the surface.

FIGURE IV

NEG. #13650-3

31 MARCH 1944

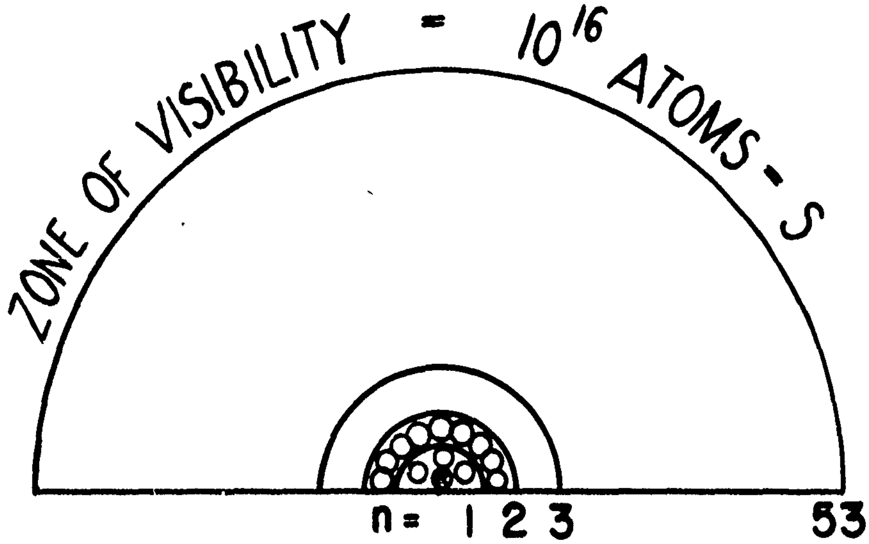


FIGURE V

16554

APPENDIX II

II. Application of Lubrication Theory to Deep Drawing

A. Introduction

In the case of the drawing of metals through dies, it may be assumed that unit pressures are very high since the forces applied must be sufficient to exceed the yield strength of the metal. It should be possible, therefore, to apply a good deal of the information on boundary and extreme pressure lubrication that has been discussed. It was previously mentioned that, in the case of boundary lubrication, friction is independent of speed over a wide range of speeds. This has been used as one criterion to determine that lubrication is of the boundary type in metal drawing. In the case of wire drawing, it has been found that friction is independent of the speed of drawing over a range of 20 to 600 centimeters per second [1]. The high frictional resistance also indicates that fluid lubrication conditions are not being obtained. In this connection, Giraud found, by immersing a wire drawing die in a calorimeter, that frictional losses were in the order of 50% [2]. Some investigations by the writer [3] have confirmed this magnitude of frictional losses in cartridge case drawing even when lubricants are used which are fairly good. This indicates that a good deal of welding must be taking place and, consequently, the methods for reducing welding discussed under extreme pressure lubrication are directly applicable to deep drawing lubrication. In addition to the large amount of heat generated as a result of frictional resistance there is also a considerable amount of heat generated due to the deformation of the metal so that it is common knowledge that work subjected to severe "cold" drawing operations comes from the dies too hot to handle with the bare hands. It is probable that surface temperatures are extremely high on the basis of the previously discussed data obtained by Bowden and Ridler. This high temperature makes boundary lubrication much more difficult because of disorientation of polar films so that in some cases the combination of high pressure and temperature makes it necessary to utilize all of the best drawing lubrication practices in order to obtain tool life that is even moderately high.

B. Effect of Some Metallurgical and Engineering Factors on Deep Drawing Lubrication

Before going into the application of the fundamentals of lubrication to drawing, it is desirable to obtain some information concerning the effect of mechanical factors upon the drawing process, as they affect lubrication. Of obvious importance is the type of metal, its mechanical properties and metallographic structure and the nature of its surface. The higher the yield strength of a metal the greater will be the force required for plastic deformation and the greater will be the unit pressures which the lubricant will be subjected to. Consequently, any factor that affects yield strength will affect lubrication. In addition, the similarity or dissimilarity of the metal being worked to the metal being used as tools to a considerable extent determines the tendency for welding between the surfaces since with dissimilar metals lubrication is less of a problem.[4]

Usually pure metals or single phase alloys can be deformed more readily than multi-phased alloys. When an alloy contains two or more constituents, the difficulties that may be experienced are dependent upon the distribution and size of the unit particles. An example may be cited to illustrate the above. Low carbon steel, which is practically a single phase alloy, contains few carbide particles and requires relatively low forces for deformation. A medium carbon steel containing fine pearlite is a two phase alloy and requires relatively high forces for deformation. On the other hand, a medium carbon steel having the same carbon content as before but having the carbon (carbide) distributed as spheroids in an alpha iron matrix requires forces intermediate between the above two conditions. For the medium carbon steel, the latter structure is more favorable so far as the lubrication problem is concerned.

In certain cases in which one of the constituents is concentrated at the grain boundaries, and becomes a continuous envelope around the grains, as is obtained when very small percentages of bismuth are present in brass, a great decrease in ductility will be experienced. In other cases, segregation of certain impurities at critical areas may be the cause of tearing of the metal. Preferred orientation, metal defects such as laminations, seams and inclusions, or excessive grain size, may also have this effect. In any event torn pieces of metal may remain in the die and cause welding, even with normally optimum lubrication. While this cause may be immediately recognized in most cases, there are times when the torn metal passes through the die after causing the trouble and the lubricant is blamed.

In attempting to attain optimum metallographic structures for desired applications, metal is annealed, normalized, spheroidized, patented, etc.[6]. The proper arrangement of these treatments is very important in determining the drawing forces and the type of lubricant that must be used for any specific operation. For a particular metallographic structure necessary to obtain certain physical properties, it is frequently possible to control these heat treating procedures so as to procure minimum forces and thus reduce lubrication difficulties. It must be understood, however, that when exceptionally high physical properties are required the metal usually cannot be treated to minimize lubrication difficulties and it is then necessary to devote greater attention to lubrication in order to obtain satisfactory performance.

Under certain conditions the hardening of metal upon storage causes difficulty, as in the case of certain age hardening alloys. Where subsequent drawing is to be conducted on such alloys, immediate redrawing should be conducted or the alloy should be stored at low temperatures and for as short a period of time as is feasible. Pure aluminum and certain of its alloys have a low rate of work-hardening and consequently may be subjected to a series of drawing operations without intermediate anneals, without requiring markedly increased drawing forces. Other metals, such as brass, plain carbon steels, and, to a greater extent, austenitic or "stainless" steel, work-harden so rapidly that they usually must be annealed between operations and may even require increased forces during part of the single drawing operation.

The formation of excessive deposits of hard non-ductile materials such as iron oxides in the case of steel, cuprous oxide in the case of brass and aluminum oxide in the case of aluminum causes local increases in the force required for deformation. When the brittle oxide coating becomes too thick it may crack as the softer metal underneath is plastically deformed resulting in the extrusion of unprotected metal to the surface where welding may take place. Excessive decarburization on the surface of steel resulting in the formation of a layer of soft pure iron also tends to weld more readily than the original steel.[5]

The occlusion of hydrogen during pickling causes steel or iron to become brittle. This embrittled steel requires higher forces for deformation and may tear during the draw. It has been reported that this hydrogen embrittlement may be reduced by heating at moderate temperatures (200-400°F.) for 5 to 60 minutes.

Regarding the surface of metals being drawn, it is advisable that this be quite smooth yet not so smooth that a mirror finish is obtained. Optimum results are usually obtained when surfaces are slightly roughened after drawing by a light pickling or sand blasting operation. This has been ascribed to the better retention of lubricant by slightly rougher surfaces. This must be balanced against the poor frictional characteristics of rough surfaces. In this connection, annealing in controlled atmosphere furnaces is frequently a source of trouble since it may result in surfaces that are too smooth.[5]

In addition to the nature of the metal being worked, the type and severity of the drawing operation determines to a considerable extent the lubrication difficulties that may be encountered. Drawing operations vary from those which consist mainly of bending or shaping, in which the stretching of the metal occurs over a relatively small portion of the total area while the reduction in area and wall thickness is very small, to those in which there is a great reduction in area and wall thickness due to ironing or flowing of the metal between tool surfaces. In the latter case, the amount of ironing and the heat generated due to crystal deformation is determined by the percentage reduction in area. In the former case, in which stretching of the metal takes place over a limited area, lubrication may be very critical since, on the other hand, too low a coefficient of friction may be sometimes disadvantageous because the ease of slippage may cause tearing or wrinkling to take place.(7)

The design of the tools is very important in determining the severity of drawing operations. Sharp corners in dies may be the cause of localized high unit pressures. The rate of reduction of the metal, i.e., the slope of the reducing portion of the die, is also important in determining unit pressures, and in this connection it has frequently been found advantageous to use longer die lands or dies placed together in tandem instead of single, short dies in which the rate of reduction of metal is high. Appropriate clearances are also important so that unnecessary sliding friction may be avoided. This is especially important because of the tendency for metals to "spring back" after being elastically deformed by the tools.

The nature, hardness, and surface condition of the tools are important factors determining the tendency toward welding of the tool with the metal being worked. The tendency for hard metals to weld is less than that for softer metals. In obtaining hard steel drawing tools a limit is reached by the maximum hardness obtainable by quenching (e.g., Rockwell C 67) and the brittleness of those hard steels upon being subjected to impact. By appropriate quenching and tempering techniques and selection of steels it is sometimes possible to obtain maximum hardness at the drawing surfaces while the bulk of the tool is much softer and supplies the necessary toughness to resist impact. However, for general practice an attempt is usually made to temper steel drawing tools to a hardness of Rockwell C 62-63 to obtain toughness as well as hardness. A difference in hardness of from Rockwell C63 to C67 has been found to cause important differences in tool life in some lubrication studies on steel cartridge case drawing made by the writer.

It is possible to increase the surface hardness of steel tool surfaces by plating chromium on the steel. While this is advantageous in many cases, it is a critical operation since excessive brittleness must be avoided and good adherance to the steel must be obtained. It is also necessary to have a hard steel surface underneath the chrome plate to prevent cracking of the plate due to plastic deformation of the steel beneath it. As a consequence, the success of chrome plating has frequently been in doubt due to wide variations in performances. However, sufficient data have been accumulated to indicate its value when used properly.(8) This is due to both its hardness and its dissimilarity to the metal being worked. The use of dies made of tungsten carbide sintered in a cobalt matrix, e.g. Carboloy, has proven very successful because the particles of tungsten carbide are almost as hard as diamond, and, in addition, are non-metallic so that the tendency for welding is considerably reduced.

Surface smoothness of tools is extremely important; the smoother the surface the better the tool life. This has been borne out by a large number of investigations[9] and in one series of experiments performed by the writer an improvement in the order of 400 percent in tool life was obtained by changing the polishing technique so that smoother surfaces were obtained. In neither case was the maximum in smoothness obtained but the improvement in tool life was, nevertheless, quite large. While maximum smoothness is desirable for tools, some intermediate roughness is ordinarily desirable for the work.

C. Lubrication Factors in Metal Drawing

(1) Excessive Welding Between the Work and Tools

When welding between work and tools takes place, even over a fairly wide area, there is usually insufficient resistance to actually stop the draw press. Instead, tearing occurs in the body of the weaker of the two metals or at the weld itself. Naturally, the tools are selected to have a higher tensile strength than the work so that, when welding occurs, there is a tendency for some of the metal being worked to be torn from its surface and deposited upon the tools. Because of the work hardening characteristics of most metals, resulting in increased tensile strength, the portion of the metal which is deposited or built up on the tools will be stronger than the metal subsequently passing over the tool. This results in further tearing within the body of the metal being worked after additional welding takes place between the build up and portions of the work. In addition, the tendency for welding between the built-up metal and the work is greater than that between the tool and work. These factors result in the build-up on the tools becoming progressively larger until it reaches such dimensions that the work is scratched or torn so that it can no longer be useful. This process is known as scoring or galling and when the welding reaches such proportion that the normal flow of metal is prevented, it is known as seizure.

(2) Prevention of Build-Up and Seizure

Welding can be prevented if a sufficient quantity of surface contaminant (lubricant) is supplied to keep the metal surfaces separated. Thus the forces of intermolecular attraction are reduced to a negligible quantity. When surfaces are under the influence of shearing stresses, the ability to perform this separation depends upon the adherence of the contaminant or lubricant to the surfaces. Depending upon the magnitude of these stresses, different types of lubricants may be employed. Thus, when unit pressures are small, mineral oil, which is held to the metal surface by forces of physical adsorption, are sufficient. When unit pressures are considerably higher, fatty acids or other polar lubricants, which are held to metal surfaces by forces of chemical adsorption and polar orientation, are usually sufficient. This type of lubricant provides sufficient protection for many drawing operations that are not very severe especially in the case of the nonferrous metals. When unit pressures become very high and, in addition, temperatures are high, it is necessary to utilize lubricants that can react with the metal to form rigidly held chemical compounds which are not appreciably affected by high temperatures. This is the type of lubricant that must be used for most severe deep drawing operations. The reactivity of the lubricant should increase as the severity of the operation is increased.

In the case of nonferrous metals, reaction with oxygen in the air is frequently sufficient to provide a stable film that is thick enough to prevent welding on a large scale. While rust or other oxides of iron are used in the case of some of the deep drawing operations performed with ferrous metals, it is usually necessary to have a more reactive extreme pressure lubricant. Oils or water-base emulsions containing sulphur, chlorine, or phosphorus of varying stages of reactivity may be utilized depending on the thickness of coating required. The heat due to deformation of the metal and to friction is depended upon to cause reaction with the metal.

In addition, chemically inert fillers may be used in the lubricant as weld preventives. These may be trapped between the work and tools and thus mechanically separate the parts. In certain more severe operations, especially with ferrous metals, it is possible to deposit a layer of dissimilar, ductile metal by electrolytic means, hot dipping, or chemical displacement.* Copper, lead, tin and, to a lesser extent, zinc have been used in this connection.[11] This method provides a layer of material that welds less readily with ferrous metal than two ferrous surfaces would and which in addition, flows with greater ease than the ferrous metal.

* In this method the reaction of iron displacing copper from a solution of its salts may be utilized. $Fe + CuSO_4 \longrightarrow Fe SO_4 + Cu$. For the procurement of reasonably good adherence of the copper to the iron, this must take place in acid medium. However, when the acidity is too high or the copper salt concentration is excessive, the copper is produced in a non-adherent form. A patented proprietary formulation which provides a bright, adherent deposit of copper is sold by the American Chemical Paint Company under the trade name of Cuprodine and consists of copper sulfate, sodium chloride, and a pickling inhibitor[10].

Welding may also be reduced by depositing on the surfaces a layer of non-metallic material, which may consist of compounds of the metal. Deposits that have been used for this purpose are sulphides, phosphates, rust, or other forms of oxide, etc. These deposits are placed upon the metal as a separate process so that it is not necessary to depend upon the drawing process to generate the heat required for reaction leading to the formation of the protective film and protection is afforded immediately as the work comes in contact with the tool. The weakness of this type of lubrication lies in the lack of ductility of these deposits which results in high lubricant friction and which may cause flaking off of the deposit during the draw. If an additional quantity of extreme pressure lubricant is not available the bare surfaces that are exposed as a result of this flaking will not receive a new deposit of stable compound and consequently welding will occur.

It has been found that when relatively thick films of low melting lubricants such as anhydrous soaps or waxes are deposited on the work in fairly adherent form, by some mechanism these films are not displaced during the drawing operation and are able to separate the metal surfaces to a considerable distance and at the same time provide a lubricant with very little resistance towards stress deformation. This results in low values for friction which tend to approach those obtained under conditions of fluid lubrication.[12] This is a promising type of lubrication which has proven very successful in the several applications in which it has been employed. Something akin to this type of lubrication is also obtained in the traditional lubrication procedure of the wire drawing industry in which a "sull" or rust coat followed by calcium hydroxide is baked on the wire and the resulting wire is coated with powdered soap prior to drawing.

One mechanism that has been suggested for this type of thick film lubrication indicates that a portion of the lubricant is trapped in some fashion so as to remain in contact with the working surface. During the drawing it is melted while the material behind it is still a solid and forms a plug preventing escape of the liquid. This explanation is not very satisfactory since the molten lubricant should transmit forces equally in all directions; these forces between the work and the tool being sufficient to exceed the yield strength of the metal. However, although the pressure at the apex of the plug might be very high, this would decrease rapidly as the width of the plug increases, since the force is transmitted over a larger area. This may explain the failure to expel the liquid.

(3) A Hypothesis on the Mechanism of Metal Build-up on Tools

The mechanism of the formation of build-up of metal on dies has been a constant source of anxiety among those who work with drawing lubricants. It is a natural reaction to the sudden occurrence of build-up on tools and scratches on work, where none was visible a few moments before, to ascribe such effects as being due to "dirt" or abrasive particles. This may have been a prime cause of the lack of progress on this subject. It is argued that there cannot be much difference among various lubricants if difficulties are due to the random influence of abrasive "dirt". While abrasive particles have some effect in causing metal build-up by exposing clean surfaces, their effect is considerably less than is generally believed.

In the following paragraphs there is presented a possible mechanism for the formation and prevention of metal build-up on tools which is a logical development of lubrication theory. This pictorial representation may serve to dispel some doubts concerning the action of drawing lubricants. In addition, it may lay the groundwork for a quantitative approach to the problem of drawing lubrication if numerical values could be determined for the various lubrication factors.

Let us consider a hypothetical case in which a die with a highly polished surface is used, a given area of which is composed of 10^{18} atoms. Since the surface would consist of peaks and valleys, possibly 10^{16} atoms are at the effective surface. If the surface of the die and work were perfectly clean these would form 10^{16} welds if the surfaces were pressed together. However, perfectly clean surfaces are almost impossible to obtain so let us assume that "shop clean" surfaces are available and only 10^{11} atoms are able to weld because of the protection afforded by miscellaneous contaminants such as oxide, water vapor, dirt etc. The die being used may be considered to be quite hard and of a dissimilar metal to the work (e.g. sintered carbide) so that only 10^7 atoms have a tendency to weld.

Consider an individual weld in Figure V. Following the formation of this weld, there is a tearing of metal in the vicinity of the weld which may be conservatively estimated as causing the build-up of three atoms from the work on the original weld. Each of the atoms picked up can weld except for the provision of surface contamination or lubrication to prevent this. Even though no visible lubricant is applied, a certain amount of surface contaminant such as oxide or water vapor etc., will be formed by the action of the atmosphere. This would possibly prevent further welding of one of the three atoms of metal built-up in spite of the increased tendency towards welding of the soft built-up metal. The other two atoms, however, would each pluck three atoms of metal from the next piece worked and the size of the welded area would increase in geometric progression. This increasing rate of enlargement of the built-up area continues in the sub-visual range but at some point the magnitude of the built-up area passes the zone of visibility, which is in the order of 10^{16} atoms or something like .00006 grams. (See Figure V).

The sum of a geometric progression is equal to $S = a\,\frac{(r^n - 1)}{(r - 1)}$
If a = 1 and each weld results in the removal of 2 atoms so that r = 2 and n = number of progressions, i.e. the number of pieces drawn in this application then

$$S = 1\,\frac{(2^n - 1)}{(1)}$$

For S, the number of welded atoms, to equal 10^{16} atoms for minimum visibility and neglecting 1 in comparison with 2^n

$$\begin{aligned} 10^{16} &= 2^n \\ n \log 2 &= 16 \\ .3n &= 16 \\ n &= \frac{16}{.3} \\ &= 53 \text{ pieces} \end{aligned}$$

Actually under practical conditions visible pick-up might occur in the first or second or third piece assuming a very difficult operation, due to the increased tendency for welding as the temperature is increased and the likelihood that more than two atoms are welded each time. The temperature would be increased considerably due to the heat generated by the plastic deformation of the metal and due to breaking of the welds by the force performing the draw.

Under the above extremely poor lubricating conditions, the rate of welding is high and metal build-up on dies grows to visible proportions with extreme rapidity and shortly afterwards to such an extent that large pieces of metal are welding and being displaced. This results in work being seriously galled and torn.

Let us now consider some cases in which various lubricants, used commercially, are applied, other conditions being similar. First let us consider soap lubrication which is adequate for cases in which the tendency for welding is at a low level but is only partially effective in severe drawing operations. A single atom from the die welds with the work and plucks three atoms of the softer metal from this. However, now we have a liquid lubricant acting as a vehicle for fatty acids which form an adsorbed layer on the welded region which is fairly resistant to shearing stresses so that it tends to prevent welding. While the polar film can sustain shearing stresses to a greater extent than hydrocarbons (mineral oil) the film is susceptible to rupture to a certain extent. This is in accord with the results of carefully controlled experiments on boundary lubrication in which it has been found that some rupture of the lubricating film with consequent welding occurs even when the best known boundary lubricants are employed.(13) Let us assume that the film in this specific region is broken once for each five pieces drawn. This results in a weld and this process is continuous, i.e. five more pieces may be drawn before temperatures and pressure cause displacement of a portion of the film to allow one weld. Utilizing the formula for geometric progressions, as before, there is obtained

$$S = \frac{(2^{\frac{n}{5}} - 1)}{(\ \ 2\ \ )}$$

for S to equal 10^{16}, n would be

$$10^{16} = \frac{(2^{\frac{n}{5}} - 1)}{2}$$

$$16 = \frac{n}{5} \log 2 \quad \text{neglecting } -1$$

$$\frac{.3^n}{5} = 16$$

$$n = \frac{16 \times 5}{.3} = 266$$

or 266 pieces could be drawn before visible pick up.

As before, this would be reduced by temperature effects but more slowly than in the previous example because the reduction in friction when polar films are adsorbed would result in the formation of less heat than when those films are absent.

The effect the superposition of various weld preventive factors would be to increase the magnitude of the number by which n is divided since the number of welds formed would be reduced more and more. Some of those factors are the use of appropriate fillers, dissimilar metal coatings, and sulfur in the lubricant to enable the formation of stable metal sulfides, etc. However, in each case the formation of visible build-up would be an abrupt affair occurring within a small number of pieces drawn. In the case in which good lubrication is attained, build-up will become visible abruptly but will become worse much more slowly than under conditions of poor lubrication.

Let us now consider a case in which all of these lubrication factors are employed.* Under this set of conditions the

* It might be pointed out that the milder the operation the fewer of these factors would be required for a desired result (tool life) but that even in these cases the use of all of the factors would cause improvement in tool life since the number of welds would be reduced. However, a practical limit is indicated by factors of expense and the occurrence of mechanical or accidental failures.

tendency for welding would be greatly lowered but would still be existant. Any or all of these factors may be in operation to prevent welding at a particular time but the tendency for welding is, let us say, one weld at this particular region for each 3000 pieces drawn. Thus, to reach the zone of visibility or 10^{16} atoms

$$10^{16} = \frac{2^{\frac{n}{3000}}}{1} - 1$$

$$16 = \frac{n}{3000} \log 2$$

$$48000 = n \log 2$$

$$\frac{48000}{.3} = n$$

$$n = 160{,}000 \text{ pieces}$$

Although only one weld would occur in 3000 pieces at this region, and the build-up would not be visible until 160,000 pieces have passed over this spot, there are 10^7 other spots on the die where this process could occur. Although visual build-up may appear at one region there probably are many thousands of other regions existant which have sub-visual build-up. These regions would become visible as additional pieces are drawn.

Before leaving this hypothesis, it should again be emphasized that it is mainly intended as a thought-provoking concept. However, it does appear plausible and may provide a better understanding of deep drawing lubrication.

(4) <u>Effect of Excessive Lubricant Friction</u>

The greatest reduction in friction is usually obtained by reduction of welding but, in addition, the friction due to the deformation of the lubricant itself sometimes becomes important. Ordinarily the power consumption reduction due to reduced lubricant friction is negligible but in cases in which are unwarranted increase of power consumption, for example, if 20% occurs - this is a factor to be considered. However, other effects attendant to increased lubricant friction may become very important such as excessive heat formation, flaking of non-ductile deposits (reactivity wear), strain on equipment and change in localized flow of the metal. Certain non-ductile deposits obtained by reaction with the lubricant during the draw or applied as pre-treatments cause excessive lubricant friction. Examples of these are heavy oxide, sulfide, "sulfur oxide", and phosphate deposits. These are frequently efficient weld preventives and sometimes can be effectively used in conjunction with a polar lubricant so as to minimize lubricant friction, although this is still high. Fillers of the pulverizing types frequently increase lubricant friction to a moderate extent. Deposits of ductile metals and of solid low melting point lubricants such as soaps or waxes generally cause low lubricant friction, the latter to the greatest extent because of the approach to fluid lubrication conditions.

(5) Effect of Lubrication on Metal Flow

In most cases the flow of metal during drawing operations is facilitated by reduction in frictional resistance and this effect is beneficial. For example, considerable impedance towards flow by excessive friction between work and dies may result in ruptures of the work due to something similar to tensile failure since part of the work is held at the die and the remainder is free to move. Not only can this type of difficulty result in tensile failure, but occasionally it can result in reduction in the thickness of the wall of the object being fabricated which may result in failure during performance.

While reduction in friction is almost always beneficial with regard to metal flow there are occasionally cases in which this is detrimental. For example, in punching out cups, Swift [7] mentions that a great reduction in friction between the punch and the work frequently results in excessive movement of the metal so that rupture of the work may occur. The proper flow of metal is most important in the cases in which hollow bodies are being formed from metal sheet such that the wall thickness of the bulk of the metal is not changed but stretching takes place over a limited area. Under these conditions, it is desirable to have this stretching take place over an area as large as is feasible. Friction reduction is generally beneficial in providing this action, but, because of this localized stretching, it is possible to have too rapid a flow of metal in some local region which may result in ruptures.

A case has been brought to the writer's attention in which dimensional control of the work is not possible until a certain amount of metal has been built up to the dies. The increased frictional resistance results in better holding of the metal in certain regions of the die. It should be emphasized, however, that this type of condition is not frequent and might be avoided by redesign of tools.

In the above discussion, the differences between the two types of frictional resistance should be kept in mind, i.e., resistance due to welding and that due to shear resistance of the lubricant. It is possible to attain various magnitudes of frictional resistance by increasing or decreasing the shear resistance of the lubricant without sacrificing tool life due to weld formation for those cases in which high frictional resistance is necessary.

The effect of different degrees of lubrication on different portions of metal being drawn has not been studied very much, but some results obtained by the writer indicate that this may be of great importance. Thus it was observed that variation of the quality of the lubricant on either the inside or outside of brass cartridge case pieces resulted in peculiar variations in drawing forces at different stages of the drawing process, indicating that the flow of metal might be changing as a consequence of changes in friction. Moreover, Swift[7] has found that, in the cupping of discs, a greater number of ruptures occurred when the top of the disc was well lubricated and the smallest number of ruptures took place when the bottom of the disc was well lubricated and the top was poorly lubricated. This effect has been confirmed by the writer, in the case of the redrawing of brass cartridge case pieces. It is believed that this subject might provide a fertile field for research investigations.

D. General Properties of Drawing Lubricants (5, 14, 15)

1. Weld Prevention

Depending upon the severity of the drawing operation, it is necessary to use a combination of the welding prevention methods discussed above. While increased improvement is usually obtained as the number of weld preventives is increased, there is a limit reached by practical considerations such as ease of application, unit cost, and occurrence of mechanical failures. Welding prevention is the most important single requirement for a drawing lubricant and has been adequately discussed in previous paragraphs.

2. Lubricant Friction Reduction

Sufficient quantities of polar lubricants should be available for reduction of lubricant friction or shear resistance of the lubricant. This requisite, which has been adequately treated in the previous discussion, plus welding prevention must be satisfied before any of the following requisites assume any appreciable importance.

3. Ease of Application

Flowing of the lubricant over the tools and work is generally the most convenient method. Dipping methods are somewhat less convenient. The use of fillers is often inconvenient since most of these require agitation to keep the filler in suspension, and tend to clog pipes and feeding mechanisms. The greatest difficulty of application occurs in the case in which deposits of low melting solid lubricant, non-ferrous metals, or stable chemical compounds are applied to the work prior to drawing but these techniques are, nevertheless, highly desirable for difficult drawing operations.

4. <u>Ease of Removal</u>

In many cases lubricants are selected on the basis of ease of removal even when other superior lubricants are available for the operation. While ease of removal must be balanced against performance, nevertheless the emphasis should be on lubrication performance. Considerable attention should be paid, if necessary to the methods for removal of good lubricants. It has been found by the writer that many instances in which lubricants are not used because of difficulty of removal can be readily cleared up by the use of appropriate cleaning methods without great changes in the cleaning procedure. Failure to emphasize good lubrication rather than easy removal is generally quite expensive in terms of tool life and quality of the finished product.

5. <u>Stability</u>

Certain lubricants tend to become rancid and, where this is due to bacterial decomposition, it is frequently possible to minimize this effect by the use of appropriate germicides. In other cases bacterial growth may be checked by means of a process similar to pasteurization of milk. Considerable care should be taken to store emulsion type lubricants under conditions in which the temperature is neither too high nor too low. Rapid changes in temperature should be especially avoided since this tends to break emulsions. It has been found that the stability of emulsion type lubricants can be greatly improved by the use of a homogenizing process, as in a colloid mill. Many manufacturers are now utilizing this treatment.

6. <u>Non-Corrosiveness</u>

Lubricants must be carefully checked for corrosiveness especially when high concentrations of fatty acids and extreme pressure additives are present. In the case of aluminum and zinc, highly alkaline lubricants must be avoided and it is for this reason that soap emulsions are generally not used in the fabrication of aluminum parts. It is usually a good idea to follow most drawing operations with a cleaning operation to remove the lubricant as soon as is feasible to reduce the possibility of corrosion taking place. This is especially true when annealing procedures are used since removal of lubricant reduces subsequent difficulties in pickling.

7. Freedom from Physiological Effect

While certain people are allergic to certain of the constituents of drawing lubricants, the occurrence of dermatitis, which has been associated with contact with drawing lubricants, has been found by the U. S. Public Health Service to be due mainly to contamination of the lubricant with bacteria or defatting of the skin. In the former case, bacteria are introduced into the lubricants by carelessness on the part of a worker or lack of cleanliness of the worker's skin.(16) In the latter case in which the skin is defatted, difficulties may be eliminated by the use of appropriate protective creams of which a large variety are now available on the market. Lubricants containing white lead should be avoided and, at the present time, there are available an ample number of non-toxic substitutes that give equal performance.

The materials frequently added to drawing compounds to mask odors due to improperly compounded reactive constituents or rancid fatty materials serve a real purpose so far as psychological effect is concerned, but when added in excessive quantities might have an adverse physiological effect. For example, one problem was brought to the writer in which a pungent material was emitted from a lubricant emulsion upon passing steam through it for the purpose of facilitating dilution with water. It was found that this was due to the presence of napthaldehyde which was substituted for benzaldehyde as a deodorant. The vapor pressure of the naphthaldehyde is less than that of benzaldehyde at room temperature, and consequently a larger quantity was used to obtain the same deodorization. However, the naphthaldehyde is distillable with steam and consequently it all came off when the compound was diluted with water at high temperatures. This was sufficient to cause the temporary hospitalization of several employees.

8. Economy

It is fairly obvious that the cost of drawing lubricants must be balanced against operation costs and that it is a foolish economy to reduce the cost of the lubricant if this results in decrease in the life of tools or in the quality of the finished product. On the other hand, high cost of lubricant is no guarantee of high quality, although many metal processors have utilized this as a criterion. In addition, proprietory formulas are, in general, overpriced whether they represent the best material for a particular job or are not especially suitable. It has been the writer's experience that after the fundamental principles of drawing lubrication are applied in selecting lubricants for various drawing operations, not only is tool life and quality of product improved but there is usually a considerable decrease in the cost of the lubricant. This is especially true when simple materials, which can be made up directly at the shop, are utilized in place of proprietory formulations. The use of the appropriate simple materials is not especially difficult if these principles of drawing lubrication are kept in mind. Another possibility that is frequently ignored in the use of superior drawing lubricants involves reduction in the number of operations required. It is economical to pay more for the lubricant if savings of this sort can be accomplished. Still another consideration involves the removal of the lubricant, and it is sometimes possible to effect savings in these operations by proper selection of the lubricant provided the performance of the lubricants is the same.

E. Types of Drawing Lubricant

Drawing Lubricants may be classified as follows:

1. Soap and water dispersions

It has been established (17, 3) that lubrication by soap dispersions is supplied almost entirely by acid soap present as a dispersed insoluble solid resulting from hydrolysis. The hydrolysis of soap may be represented as follows:

$$\underset{\text{(soap)}}{Na\,S_p} \rightleftarrows Na^+ + \underset{\text{(fatty acid ion)}}{S_p^-}$$

$$H_2O \rightleftarrows OH^- + H^+$$

$$H^+ \rightleftarrows HS_p + NaS_p \longrightarrow \underset{\text{(acid soap)}}{NaS_p \cdot HS_p}$$

This hydrolysis is the cause of the high alkalinity (pH = 10.2 to 11.0) of "neutral" soaps when dispersed in water at low concentrations. However, any appreciable excess of alkali should be avoided as this represses the hydrolysis. The acid soap, formed as above, being only slightly soluble, the above reaction proceeds to an appreciable extent depending upon the concentration and temperature; the lower the concentration, and the higher the temperature, the greater the hydrolysis, except insofar as the solubility of the acid soap is increased at higher temperatures. The soaps that are generally recommended for use as drawing lubricants have fatty acids of relatively high titer, i.e., solidification point, made from fats rather than oils. Since these soaps form acid soaps that are less soluble than those formed from low titer fatty acids, this recommendation is ordinarily a proper one. However, any soap can be used if attention is paid to accomplishing maximum hydrolysis, such as by using low concentrations.

While practically complete hydrolysis can be attained by sufficient dilution for the formation of an effective lubricant dilution should be stopped considerably before this point so as to have a certain amount of unhydrolyzed soap available to disperse the acid soap. It might be mentioned that many metal-forming establishments consider that a soap having a heavy gel structure is necessary and use the "slippery" feeling obtained with such dispersions as the criterion of a satisfactory lubricant. While it is frequently true that soaps that tend to form heavy gels are also the most effective producers of acid soap. it is generally advantageous to utilize those soaps at such a low concentration that the gel structure does not form.

2. Soap, fatty acids and water

Since the effective constituent of soap dispersions is the acid soap, it appears obvious that additions of fatty acids to soap so as to increase the acid soap content would supply more efficient lubricants. This improvement has been observed to a limited degree in laboratory performance tests[18] but this type of lubricant has not been employed widely in metal drawing.

3. Soap, fatty oil or fat, free fatty acid, and water

This is the conventional type of drawing lubricant and is used extensively for all sorts of drawing operations under various proprietary names. While the free fatty acid may be added, it is more customary to utilize fatty materials that are partially decomposed into fatty acids, since this enables the use of cheaper materials. It has been claimed that the fatty acid is added to "wet" the metal but it is more probable that the soap and fatty materials are acting as a vehicle for this free fatty acid which lubricates by the formation of polar adsorbed films. Other portions of the lubricant, notably water, also contribute towards lubrication during drawing.

It is advantageous to use as much fatty acid as possible without causing excessive corrosion. Relatively large variations in soap and fat content usually cause little change in lubrication properties and it appears that one of the main functions of the fat or fatty oil is to form an emulsion with the soap and thus inhibit the natural foaming tendencies of the soap dispersion. It has been found, in many cases, that the use of soap dispersions in conjunction with an anti-foaming agent is equally satisfactory to this conventional type of drawing lubricant.

4. Soap, Mineral Oil, and Water

In lubricants of this sort there is a change in the physical properties of the soap due to the formation of the emulsion, including foam reduction, but the sole source of fatty acids is still the soap. It has not been determined whether the tying up of the soap in the emulsion causes a decrease in the available free fatty acid. This type of lubricant has been used mainly as a coolant.

5. <u>Soaps, Mineral Oil, Fatty Acids, and Water</u>

In lubricants of this sort the mineral oil is used as a vehicle for the fatty acids and for changing the physical properties of the soap by formation of an emulsion. The mineral oil is frequently used surreptitiously in place of the fatty oil in the lubricant listed in 3 above, because of the physical similarity between the lubricants. However some of these lubricants compare favorably in performance with the emulsions containing fatty material. In fact, these lubricants should have certain advantages since the absence of fatty material should cause a reduction in the cost of the lubricants, and should reduce rancidity. However, this reduction in cost is not passed on to the consumer in many cases. It should be mentioned that mineral oil is frequently only partially substituted for the fatty material in the lubricant listed above. In this case, it is usually intended as an adulterant, but from a practical standpoint there is very little difference in performance and this practice may be condoned if at least part of the cost reduction is passed on to the consumer.

The lubricants listed in 1 to 5 may be used as substrata for the addition of other constituents required for lubrication in severe drawing operations. These additions may contain reactive constituents such as sulphur, chlorine, and phosphorus in their various stages of reactivity, fillers, etc.

6. <u>Lubricants of the above types plus Reactive Constituents</u>

While chlorine and phosphorus are used to a certain extent, the most common reactive constituent which is added to water base emulsions is sulphur. When sulphur is used in its elementary form it functions partially as a reactive constituent and partially as a filler. The sulphur added as a portion of sulphurized oils may have initially varying reactivity. However, because of the high alkalinity of soap emulsions, there is a considerable reduction of reactivity of each of the sulfurized oils in comparison with the same oils in oil or water. In fact, the reactivity of chlorine and phosphorus bearing compounds are sometimes reduced so much by the high alkalinity of soap dispersions that they are ineffective as extreme pressure lubricants in this medium.

7. <u>Lubricants of the Above Types Plus Fillers</u>

The fillers that are most frequently used are; chalk, lithopone, zinc oxide, clay, white lead, flour, yeast, bran, talc, graphite, and mica. These materials tend to separate mechanically the metal surfaces insofar as they can adhere or can be trapped between these surfaces which are being subjected to high shearing stresses. One consideration of the use of compounds containing fillers involves the tendency for sedimentation to take place thereby removing the filler from the sphere of action. This being the case, it is usually necessary to use the above emulsions in concentrated forms so as to increase the viscosity of the medium and thus retard sedimentation. Thickening agents may also be utilized to increase the viscosity of the medium, some of these being: starch, flour, gelatin, and sodium alginate. In general, two types of inorganic fillers are employed, namely, those that pulverize upon being subjected to high pressure and those that have weak cleavage planes so that slippage along these planes takes place when they are subjected to high shearing stresses. Examples of the former are chalk (whiting), lithopone, and white lead and examples of the latter are graphite, talc, and mica. The former type results in greater lubricant friction than the latter type but are probably more efficient as mechanical separators of sliding surfaces. In the latter case, the force required to cause slippage at the weak cleavage planes is usually relatively small so that impedence to motion is not as great as in the case in which a crystalline material must be crushed before motion can take place. In the use of fillers in soap and water media, attention must be paid to the solubility of the fillers, so that the soap is not precipitated as alkaline earth or heavy metal soaps. This difficulty is experienced to a great extent with gypsum. Organic fillers such as bran are used in certain wire-drawing lubricants and offer the advantages of high adhesiveness and softness.

It has been found that a good many lubricants containing fillers contain surprisingly large quantities of abrasive particles due to the use of natural sources of the fillers. Many of these particles are coarser than the bulk of the filler since they are ground with greater difficulty. Consequently these large particles would sediment and have no effect on lubrication. Nevertheless, a considerable number of abrasive particles are frequently present in the effective sphere of action of the fillers. This effect has not been completely evaluated, but some work has indicated that in metal drawing these abrasive particles are less detrimental than would be expected. In certain instances it is even desirable to have a filler that is somewhat abrasive so as to prevent excessive slippage of the metal[20].

8. <u>Lubricants Containing Emulsifying Agents other than Soap</u>

In cases in which emulsions must be manufactured or used with hard water it is possible to utilize other emulsifying agents than soap. While these emulsifying agents have good surface active properties they frequently are relatively poor lubricants and are inferior to soap from this viewpoint. This also applies to "soluble oils" widely used for metal cutting which generally have petroleum sulphonates as emulsifying agents.

9. Mineral Oil

Mineral oil alone is quite unsatisfactory as a drawing lubricant except for the mildest drawing operations. Even in these cases the mineral oil should be not very well refined since the small amount of polar material present in crude oil, which provides some boundary lubrication properties, tends to be removed during the refining process. Mineral oil obtained from some crude oils such as "Smackover Crudes" contain relatively large amounts of sulfur. Although of low reactivity, this sulfur imparts some small extreme pressure lubricant properties to these oils. The cooling properties of petroleum oil base lubricants dependent to a considerable extent upon the viscosity of the oil, which should be low for better cooling although not so low that the flash point is below 275°F.

10. Fatty Oil

Fatty oils have been used quite extensively in deep drawing operations, the most commonly used material being lard oil. It appears that water base lubricants can be substituted for fatty oils without any loss in performance in many cases. Consequently fatty oils are rapidly being displaced as drawing lubricants since they cannot compete with the water base lubricants on the basis of cost and ease of removal. In many cases in which fatty oils are used, it is possible to substitute mixtures of fatty oil and mineral oil provided that the content and type of free fatty acid are adjusted so as to be the same and the percentage of fatty oils is not too low. The advantages of mineral-fatty oil combinations over straight fatty oil are lower cost, less gumming, and less rancidity. There is some evidence that the performance of fatty oils is governed to a considerable extent by the amount and type of free fatty acids, present as a result of hydrolysis of the oils by bacterial or other action, but there are other constituents that make important contributions towards lubrication.

11. Oil Base Lubricants plus Reactive Constituents

Additives containing sulphur, chlorine, or phosphorus are frequently incorporated into the oil lubricants just discussed to supply lubrication under more severe drawing conditions. In these cases minor percentages of fatty oil may be used advantageously --- the mineral oil acting as a vehicle and the fatty oil yielding a polar lubricant to reduce friction due to the stress deformation of the solid film that is formed. Reactive constituents of varying activity may be used to fit the severity of the drawing operations.

12. <u>Oil Base Lubricants Containing Fillers</u>

Fillers may be incorporated into the above lubricants to increase the weld preventive properties of the lubricants. One lubricant which was extensively used in the early phases of deep drawing was white lead plus linseed or castor oils. The use of this lubricant has been practically discontinued because of the poisonous nature of the white lead and the difficulty of removing the lubricant. Chalk (whiting) is now used extensively as a filler and frequently lithopone is used as a substitute for white lead. Other fillers that are used are talc, graphite, and mica. Colloidal graphite dispersed in mineral oil has found wide application.

13. <u>Low Melting Point Solid Lubricants</u>

In the case of wire drawing in which a "sull" or rust and lime coating is employed, it is customary to utilize powdered soaps as the lubricant applied at the dies. In this case, the wire is allowed to dip into the soap powder which adheres to the wire. This is carried to the dies and is generally converted to a transparent adherent coating which frequently enables the wire to be drawn through several dies without relubrication. Since it is necessary for the soap powder to adhere to the wire in order to be carried into the dies, one of the most important properties that the soap powder must have is a resistance to the adsorption of water in the atmosphere which would result in clumping of the soap powder. For this reason soaps used for this purpose should be substantially free of glycerine[19] or other humectants; soap builders such as soda ash or borax are frequently added. These built-up soaps are frequently relatively ineffective in water media because of the prevention of hydrolysis by the excess alkali of the soap builder. Great care should therefore be exercised in attempting to utilize soaps designed for dry wire drawing for wet drawing. In an extensive study of wire drawing soaps, Francis[19] found that sodium soaps high in saponified fatty acid content and low in glycerides and moisture were best while potassium soaps were very poor.

While soap is used in powdered form in wire drawing, in certain other drawing operations, it has been found advantageous to utilize dried soap coatings which are introduced onto the surface of the work by immersion of the work in a hot concentrated solution of soap followed by air drying or baking. This results in a thick coating, in contrast to boundary films, of a material which is readily plastic and which is probably changed to liquid form during the drawing operation[12]. The decrease in the coefficient of friction and prevention of welding due to the attainment of thick film lubrication results in long tool life and low power consumption.

In using this technique, it is necessary to attain good adherence to the basic metal. For this reason the surface of the metal must be clean and it has been found advantageous in at least one instance to have the surface slightly roughened. For example, Williams (12) has found that the application of a light film of mineral oil prior to a wax coating resulted in failure to obtain the good performance of dried wax deposits.

It is possible to use other materials in place of dried soap with similar beneficial results. Waxes have been used in this manner either deposited from a solvent or from an emulsion. Fillers or reactive constituents or both may also be incorporated into these emulsions.

14. Solid Lubricants

A lubricant that has been used for severe drawing operations on ferrous metals consists of the stable compounds formed by the action of sulphurized oils or fats, which are heated with the metal with a considerable quantity of water being present. This results in a film of stable chemical compound consisting of sulfides or partially oxidized sulfides. Corrosion is inhibited and friction reduced by the layer of oily material formed at the same time. This lubricant is used alone but occasionally a coolant is circulated in conjunction with it.

Coatings of rust formed in such a manner that the oxide is hydrated, and therefore not abrasive, are extensively used as deep drawing lubricants in conjunction with liquid lubricants containing polar molecules such as fatty acids. The sull coating used in the wire drawing industry is of this type although this is used in conjunction with lime and baked to neutralize the acid used to cause the rust and to remove occluded hydrogen that embrittles the metal. In the case of non-ferrous metals, oxide coatings are also used extensively, although it is frequently not realized that this is the case and some inefficient empirical method of application is frequently employed. For example, work is often stored for long periods of time for this reason.

Phosphate deposits have been applied to many deep drawing operations usually in conjunction with a liquid lubricant although in at least one application it has been reported that no other lubricant was used.

It may be mentioned that while thick-films of soaps, waxes, sulfide, rust, and phosphate coatings satisfy the primary objective of lubrication, that is, the separation of surfaces so as to prevent welding, the last three treatments result in a high order of lubricant friction because of the necessity of deforming relatively brittle deposits.

15. Metal Lubricants

In certain severe drawing operations especially in the case of ferrous metal, there is frequently interposed between the work and tool a layer of a dissimilar, ductile metal. Copper, lead, zinc, and tin have been used in this connection, application being by electrolytic means, hot dipping, or chemical displacement. This type of lubrication has been discussed earlier in this paper. Non-ferrous metals are also used in powder form as fillers incorporated into water or oil base lubricants. Aluminum, copper, brass, and lead have been used in this manner. It is, of course, necessary to have the metal in a very finely divided state.

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